INVESTIGATION ON THE REMOVAL OF PARAFFIN WAX DEPOSITION BY MAGNETIC FIELD

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CERTIFICATION OF APPROVAL

Investigation on the Removal of Paraffin Wax Deposition by Magnetic Field

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NURHAKIMAH MOHD AMAN

ABSTRACT

Paraffin wax deposition creates problem to the surface facilities. One of the solutions to this problem is by applying magnetic field technology to reduce the viscosity. The effects of a magnetic field on aggregates to control paraffin wax deposition have been reviewed in technical literature. Chai Set Lee, Use of Magnetic Field in Paraffin Wax Deposition Control for Surface Facilities (2008) reported an experimental study on the influence of magnetic field on wax deposition removal and viscosity reduction. Chai Set Lee reported the configuration where the pipe is placed along the length of each magnet, on top of the pipe are both South poles while at the bottom are the North poles displayed the best magnetic field lines where all the line were at the right angle to the direction of force, this new cumulative force is bigger and acting at the same direction. This configuration is used in the wax removal experiment with different number of magnets, crude oil flow rate and temperature. However, experts in scale and paraffin control from industry leaders like Schlumberger, Nalco Chem and etc. believed that the magnetic field is something new and still in R&D stage where it is not proven in real applications. Thus, the objective of this exploration study is to find more scientific explanation on the effects of varies the numbers of magnets and the effects of applying different temperature and flow rate of crude oil in paraffin wax deposition control. Within the scope of this work the theme of magnetic technology control paraffin wax deposition is discussed based on preliminary laboratory and field results. From the results obtained in the experiments, it has been proven the effect of using magnetic field which reduces paraffin wax deposition by 2%. The efficiency of the magnetic field can be improved with some modification to the magnet strength, the crude oil flow rate and temperature. Results from this study hopefully will have significant impact in the industry to solve problems in crude oil production and transportation. This new investigation is proposed to be advance studied on the effect of magnetic field which could produce precise scientific explanation on the whole process.

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TABLE OF CONTENTS

CERTIFICATION i

ABSTRACT iii

ACKNOWLEDGEMENT iv

CHAPTER 1: INTRODUCTION 1
- 1.1 Background 1
- 1.2 Problem Statement 1
- 1.3 Objectives 2
- 1.4 Scope of Study 2

CHAPTER 2: LITERATURE REVIEW 3
- 2.1 Petroleum Chemistry and Crude Composition 3
  - 2.1.1 Paraffins 4
  - 2.1.2 Naphthenes 4
  - 2.1.3 Aromatics 5
- 2.2 Waxy Crude Composition . . . 6
  - 2.2.1 Paraffin Precipitation . . . 7
  - 2.2.2 Formation of Paraffin Wax Deposition 8
- 2.3 Paraffin Wax Deposition Problem . . 10
- 2.4 Magnetic Field 11
  - 2.4.1 Magneto-hydrodynamics . . 13
  - 2.4.2 Theoretical Discussion on Magnetic Fluid Conditioners 13
- 2.5 Paraffin Wax under Magnetic Field . . 15
- 2.6 Paraffin Wax Deposit Test . . . 17
- 2.7 Application of Surface Unit . . . 18

CHAPTER 3: METHODOLOGY 19
- 3.1 Project Milestone 19
- 3.2 Process Flow Chart 19
- 3.3 Experimental Samples 21

3.4 Experimental Procedures . . . 21
3.4.1 Wax Deposition Removal . . 21
3.4.1.1 Materials and Equipment . 21
3.4.1.2 Experiment Procedure . 22
3.4.1.3 Experiment Setup . . 24

CHAPTER 4: RESULTS AND DISCUSSION . . . 26
4.1 Flow Rate 26
4.2 Magnetic Flux Density . . . 27
4.2.1 Sample Results for Valve Fully Opened at 25°C with 4 Unit Magnets . . 27
4.2.2 Magnetic Flux Density for All Operating Conditions 29
4.3 Wax Deposition Removal . . . 29
4.3.1 Sample Results for Valve Fully Opened at 25°C with 4 Unit Magnets. . 30
4.3.2 Results for All Operating Conditions 31

CHAPTER 5: CONCLUSION 34

CHAPTER 6: RECOMMENDATION 36

REFERENCES 37

APPENDICES 39
Appendix 1: Flow Rate when Valve Fully Opened 39
Appendix 2: Flow Rate when Valve Three Quarter Opened . . . 39
Appendix 3: Flow Rate when Valve Half Opened 39
Appendix 4: Magnetic Flux Density for Pair S1&N1 (Valve Half Opened at 25°C with 4 Unit Magnets) 40
Appendix 5: Magnetic Flux Density for Pair S2&N2 (Valve Half Opened at 25°C with 4 Unit Magnets) 40
Appendix 6: Magnetic Flux Density for Pair S1&N1 (Valve Three Quarter Opened at 25°C with 4 Unit Magnets) . . 41

Appendix 7: Magnetic Flux Density for Pair S2&N2
(Valve Three Quarter Opened at 25°C with 4 Unit Magnets) . . 41
Appendix 8: Magnetic Flux Density for Pair S1&N1
(Valve Full Opened at 30°C with 4 Unit Magnets) 42
Appendix 9: Magnetic Flux Density for Pair S2&N2
(Valve Full Opened at 30°C with 4 Unit Magnets) 42
Appendix 10: Magnetic Flux Density for Pair S1&N1
(Valve Full Opened at 35°C with 4 Unit Magnets) 43
Appendix 11: Magnetic Flux Density for Pair S2&N2
(Valve Full Opened at 35°C with 4 Unit Magnets) 43
Appendix 12: Magnetic Flux Density for Pair S1&N1
(Valve Full Opened at 40°C with 4 Unit Magnets) 44
Appendix 13: Magnetic Flux Density for Pair S2&N2
(Valve Full Opened at 40°C with 4 Unit Magnets) 44
Appendix 14: Magnetic Flux Density for Pair S1&N1
(Valve Full Opened at 25°C with 2 Unit Magnets) 45
Appendix 15: Magnetic Flux Density for Pair S2&N2
(Valve Full Opened at 25°C with 2 Unit Magnets) 45
Appendix 16: Wax Removed Percentage for Different Valve Opening . 46
Appendix 17: Wax Removed Percentage for Different Crude Oil Temperature 46
Appendix 18: Wax Removed Percentage for Different Number of Magnet . 47
Appendix 19: Material Safety Data Sheet for Dulang Crude Oil . . 48

LIST OF FIGURES

Figure 2.1: Feedstock Composition Represented by the Distribution of Chemical Types 3
Figure 2.2: Isooctane Molecular Structure 4
Figure 2.3: Methylcyclopentane Molecular Structure 4
Figure 2.4: Cyclohexane Molecular Structure 4
Figure 2.5: Benzene Molecular Structure 5
Figure 2.6: Indane Molecular Structure 5
Figure 2.7: Pure Paraffin Crystal Morphology 17
Figure 2.8: Pure Paraffin Crystal Morphology Magnetically Treated . 17
Figure 2.9: Surface Unit on Production Line 18

Figure 2.10: Surface Unit on Production Battery 18
Figure 2.11: Surface Unit at Oil Transfer Station 18
Figure 3.1: Final Year Project Milestone 19
Figure 3.2: Final Year Project Process Flow Chart 20
Figure 3.3: Measurement Points 23
Figure 3.4: Magnets Arrangement 24
Figure 3.5: Actual Experiment Setup 25
Figure 4.1: Graph of Wax Removed Percentage versus Time for Different Crude Oil Flow rate 31
Figure 4.2: Graph of Wax Removed Percentage versus Time for Different Crude Oil Temperature 32
Figure 4.3: Graph of Wax Removed Percentage versus Time for Different Number of Magnet 33

LIST OF TABLES

Table 3.1: Variable Parameters 24
Table 4.1: Flow Rate for Valve Fully, Three Quarter and Half Opened . 26
Table 4.2: Pair S1 and N1 27
Table 4.3: Pair S2 and N2 28
Table 4.4: Summary of Magnetic Flux Density 29
Table 4.5: Summary of Mass for Pipes 30
Table 4.6: Mass of Pipes over Time 30
Table 4.7: Percentage of Wax Removed over Time 31

CHAPTER 1

INTRODUCTION

1.1 Background

Wax deposition during paraffinic crude oil production and transport is one of the most serious problems faced in surface operations. This area is still open to considerable improvement given a fundamental lack of knowledge on the shear stresses which apply at a pipe wall under turbulent flow, relationship of viscosity, velocity and shear rate to wax transportation and even the mechanism by which wax actually adheres to a pipe wall and deposition continues.

Many research has been done to justify that magnetic field can remove the paraffin wax deposition. Thus, this project is developed to investigate the removal of wax using magnetic field. Approach used is by interviewing industrial experts, studying literature review and running experiments. The strength of the magnets, the flow rate and the operating temperature of the crude oil is taken into consideration to study the effect of crude oil temperature, flow rate and strength of magnets to the magnetic field in paraffin wax deposition control.

1.2 Problem Statement

Magnetic field technology is one of the new techniques developed to solve paraffin deposition problem in crude oil production. Well known consultants like Ranhill Worleyparson and MMC Oil and Gas seems that this technology is still under trial since there is not much information about it. They claimed that it looks like it is being tested as a preventive solution to wax deposition, while currently the process is to let the deposition occur in the system before it was removed through heating, with the used of solvents, or scraping. In a Flow Assurance Workshop few years ago organized by Society of Petroleum Engineers, experts on ion scale and paraffin control from industry leaders like Schlumberger and Nalco Chem believed that the magnetic field is something new and still in research and development stage where they claimed that this technology is not proven in real application. This claim was supported with evidence from PETRONAS Carigali Sdn Bhd who has installed 3 units of Enertec Linear Kinetic Cell Paraffin Control System. The equipment was not used for paraffin control but for scale prevention. It has been installed for more than a year but provides no evidence that the equipment manage to prevent scale build up. They claimed that the magnetic field can prevent scale or paraffin build-up to a certain extent but nobody can say exactly. As far as they concern, they are relying on chemical and heat. Wax deposition is a common problem and using magnetic field is a new technology solution, which was presented earlier by a company from China and still, it is unproven at that time. Till nowadays, all the solution tends to be on chemical side, which is not environmentally attractive. Definitely, there is not enough evidence because this is a new technology, thus this is one of the reason to advance the research. This project is to be further investigated to provide more evidence on the effectiveness of this technology.

1.3 Objectives

Objectives are goals to be achieved throughout this study. Several objectives have been identified to keep the project moving in the right direction:

- to study on crude oil composition and the formation of paraffin wax deposition,
- to investigate the paraffin wax behavior under magnetic field, and
- to investigate the effect of the strength of magnet, the crude oil temperature and flow rate on wax removal rate.

1.4 Scope of Study

Subjects on paraffin wax deposition process and the effect of the strength of magnet, the crude oil temperature and flow rate on wax removal rate will be further studied. Experiments will be conducted with a magnetic fluid conditioner to produce magnetic fields in a pipeline with flowing crude oil and a pump to flow the crude oil. This is to ensure the results obtained later will be applicable to the industry with relevant adjustments. Significant recommendation will be generated for further enhancement from the analysis obtains from the result gathered.

CHAPTER 2

LITERATURE REVIEW

2.1 Petroleum Chemistry and Crude Composition

The hydrocarbons that comprise crude oil are paraffins, naphthenes (cycloparaffins) and aromatics. These hydrocarbons share some structural features but differ in the ratio of hydrogen to carbon atoms and how those atoms are arranged. Olefins are not present in crude oils and are formed from rearrangement of atoms during the cracking process to produce gasoline-blending streams. Paraffins occur in higher concentrations in lower boiling fractions of crude oil while the concentration of naphthenes (cycloparaffins) and aromatics increase at higher boiling ranges as shown in figure 2.1 below. *(American Petroleum Institute, 2003)*

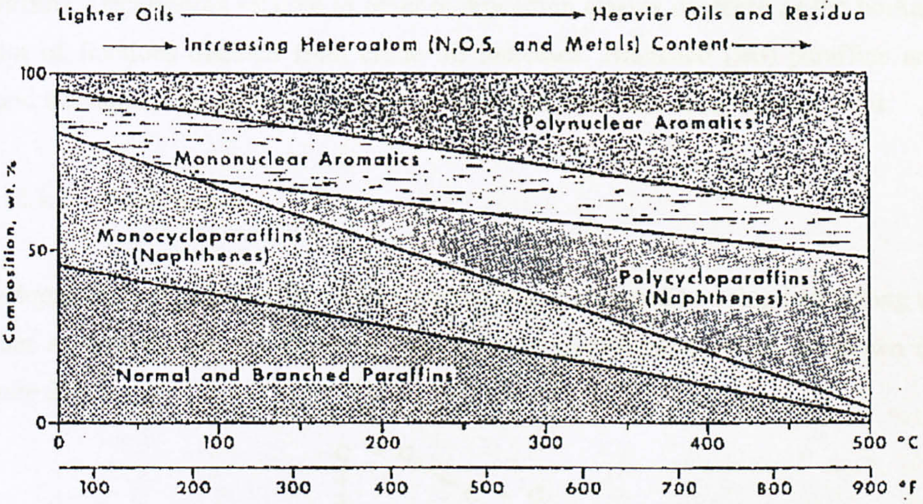
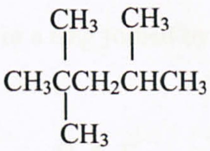


Figure 2.1: Feedstock Composition Represented
by the Distribution of Chemical Types *(Mobil, 1997)*

Hydrocarbon molecules in crude oil may include from 1 to more than 50 carbon atoms at room temperature. When isolated, hydrocarbons containing 1 to 4 carbon atoms are gases, those with 5 to 19 carbon atoms are usually liquid, and those with 40 or more carbon atoms are solids. *(American Petroleum Institute, 2003)*

2.1.1 Paraffins

Paraffin structural arrangement is C_nH_{2n+2} where n= number of carbon atoms. Carbons are joined by single bonds (e.g. butane, $CH_3CH_2CH_2CH_3$). Paraffins with 4 or more C atoms may have 2 or more structural arrangements or structural isomers, for example normal octane, $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$ or isooctane, as shown in figure 2.2 below. *(American Petroleum Institute, 2003)*



$$CH_3\overset{CH_3}{\underset{CH_3}{C}}CH_2\overset{CH_3}{C}HCH_3$$

Figure 2.2: Isooctane Molecular Structure

Normal paraffins occur in most crude oils but in varying total concentrations *(King, 1983)*. As a rule, crude oils of older geological age contain higher quantities of n-paraffins. Occurrences relative to other hydrocarbon classes decrease as the boiling point of fractions distilled from crude oil increases. Branched (iso) paraffins are found throughout the boiling range but do diminish with increasing boiling point.

2.1.2 Naphthenes

Cycloparaffins in gasoline have 5 or 6 carbon atoms arranged in a ring and belong to either a cyclopentane, as shown in figure 2.3 or cyclohexane series, as shown in figure 2.4.

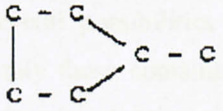


Figure 2.3: Methylcyclopentane Molecular Structure

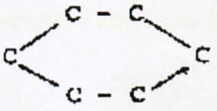


Figure 2.4: Cyclohexane Molecular Structure

Cycloparaffins constitute a substantial proportion of petroleum with 5 to 6 membered ring structure being the predominant type. Most individual cycloparaffins that have been isolated are in the boiling range of gasoline and kerosene. The cycloparaffin portion of lubricant fractions is a complex mixture of non-condensed and condensed 5 and 6 member rings. *(American Petroleum Institute, 2003)*

2.1.3 Aromatics

Some carbon atoms are arranged in a ring joined by aromatic bonds such as benzene, C_6H_6 (refer figure 2.5).

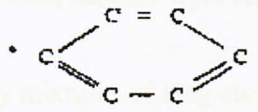


Figure 2.5: Benzene Molecular Structure

In polycyclic aromatics, some carbons are shared by 2 or more rings such as indane, C_9H_{10} (refer figure 2.6).

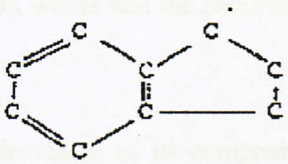


Figure 2.6: Indane Molecular Structure

Aromatic hydrocarbon types appear to be present in the same relative proportions in different crude oils. Where several possibilities for alkyl substitution exist, the predominant isomers are generally those containing substituents with the smallest number of carbon atoms. In heavier, lubricant type fractions, mixed aromatic-cycloparaffin hydrocarbons predominate, as mono-, di-, or trinuclear aromatic-cycloparaffin hydrocarbons. *(American Petroleum Institute, 2003)*

2.2 Waxy Crude Composition

In general, petroleum fluids can be classified into four major fractions denoted as saturates, aromatics, resins, and asphaltenes. Saturates are non-polar and consist of normal alkanes (n-paraffins), branched alkanes (iso-paraffins) and cyclo-alkanes (naphthenes). Examples of each of these classes of chemicals along with the aromatics, resins and asphaltenes have been reported elsewhere *(McCain., 1990; Cruse et al., 1960; Lira-Galeana et al., 2000)*. Saturates are the largest single source of hydrocarbon or petroleum waxes, which are generally classified as paraffin wax, microcrystalline wax and/or petrolatum *(Warth, 1956)*. Of these, the paraffin wax is the major constituent of most solid deposits from crude oils.

Paraffin waxes are essentially mixtures of long-chain n-paraffins, C_nH_{2n+2} or just C_n herein with carbon chain lengths ranging from C15 to C75+ (Allen et al., 1989, Srivastava et al., 1993; Hunt, 1996). Asphaltenes and residual oil components often co-precipitate with the paraffin waxes and result in varying appearance (color) and texture to the precipitated solids. In general, only small amounts of aromatic components co-precipitate with waxes and the resulting solid material usually melts by applying heat.

Petroleum wax crystal size decreases as its composition becomes more complex. Typical wax crystals precipitated from real crude oils are indeed much smaller than those crystallized from “model” solvents or simple mixtures *(Anderson et al., 2001)*. The heavier n-paraffin molecules are significantly more concentrated in the wax deposit than in the parent oil. The observed humps beneath the patterns of n-paraffins peaks are presumably ascribed to the presence of branched and cyclic paraffins as well as aromatics *(Fuhr et al., 1999)*. The n-paraffin peaks at retention times below 20 minutes are clear indication of the presence of trapped/occluded oil in the wax deposit.

There are three ways identifying waxy crude:

- Viscosity of crude increases as temperature of crude oil slowly reduced.
- Cloud point, temperature when first crystals begin to appears, a visual observation for lighter crude oils.
- Pour point, temperature at which the crude oil ceased to flow.

(Jay Paktinat, 2002)

2.2.1 Paraffin Precipitation

While the precipitation may be defined as the formation of a solid phase out of a liquid phase, deposition can be described as the formation and growth of a layer of the precipitated solid on a surface. Precipitation although a precursor to deposition, does not necessarily ensure deposition. Moreover, whereas the precipitation is mainly a function of thermodynamic variables such as composition, pressure and temperature, the deposition is also dependent on the flow hydrodynamics, heat and mass transfer, and solid-solid and surface-solid interactions. *(Ahmed Hammami et al, 1999)*

Precipitation and deposition of wax are associated to phase equilibrium of hydrocarbons and to fluid-dynamics conditions of flow, respectively. The paraffining becomes one function of petroleum intrinsic characteristics and temperature, velocity and pressure variations during the production. The appearance of a solid phase in petroleum and the subsequent wax deposition are related to changes in the separation hydrocarbons, or a mixture thereof, having the general chemical formula C_nH_{2n+2}, wherein an integer between and including 22 and 27. *(Terence Borst et al., 2008)*

Paraffin waxes are semi-crystalline in nature and tend to crystallize/precipitate from crude oils at and below the equilibrium solid-liquid temperature (thermodynamic cloud point). Crystallization is the process whereby an ordered solid structure is produced from a disordered phase, such as a melt or dilute solution (e.g. crude oil). It usually involves two distinct stages, namely nucleation and growth which may be considered separately *(Hammami and Raines, 1999)*.

2.2.2 Formation of Paraffin Wax Deposition

The flow of wax formation is as below:

- Long chain n-paraffin form macrocrystalline structures on cooling.
- Straight chains interlock with each other forming thin flat plates.
- Plates attach to each other and set up across-linked cage-like net work.
- Wax matrix becomes sufficient to solidify crude.

Jay Paktinat (2002)

The paraffin deposition formation can vary from very minor to extremely severe depending on the paraffin wax content of the crude oil, the cloud and pour points of the crude, and the operating temperature *(Tuttle and Robert N., 1983).*

- Cloud Point and Pour Point

High pour point crude oil will present congealing problems in most ambient conditions *(Peter K.W. Herh et al., 2003).* Waxy crude oils, which contain significant proportions of heavy paraffin compounds, are known to produce a gel-like structure when the crude oils are cooled below their pour point *(Jose' A. Lopes da Silva et al., 2004).*

The thermodynamic cloud point is defined as the highest temperature at which a solid phase (i.e., wax) will exist at a given pressure. It is a point on the solid-liquid phase envelope. Measured cloud point, on the other hand, is the temperature at which a detectable amount of a solid phase forms upon cooling in the time frame of the measurement at a given pressure *(Karan et al., 2000; Ratulowski et al., 2000).*

The measurement of cloud point depends on a number of factors including oil composition, thermal history, pressure, shear environment, measurement technique, and cooling rate *(Hammami and Raines, 1999).*

It is conceivable that the heaviest n-paraffin present in the oil has a dramatic effect on the cloud point and the higher the paraffin decay (defined as the ratio C_n/C_{n+1}) is, the more difficult the detection of the true cloud point that lies at the end of a very long and thin tail will be *(Ahmed Hammami et al., 1999*).

R. M. Jorda stated that paraffin deposits collect on the surface of sucker rods and tubular in oil wells and flow lines when these surfaces and the adjacent production stream are cooled below the cloud point temperature of the produced hydrocarbon stream. This causes wax to precipitate from solution and collect in irregularities on the surfaces. Because the freshly precipitated wax is sticky, these particles cling to one another to build a continuous layer of paraffin. The maximum thickness of this layer is governed by such factors as fluid flow velocity, heat transfer and cohesive strength of the paraffin.

- Paraffin Wax Content

The n-paraffins are flexible hydrocarbon molecules and, hence, tend to align/cluster together upon cooling and precipitate from crude oil as "stable" wax solids. The iso-paraffins are also flexible hydrocarbon molecules; however, the corresponding side chains tend to delay the formation of wax nuclei (i.e., depress the cloud point) and usually form unstable wax solids (crystals with defects). Cyclo-paraffins, also known as naphthenes, are stiff (least flexible) and bulky in nature; they tend to disturb and/or disrupt the wax nucleation and growth processes. The corresponding wax crystals are the least stable saturates (of the microcrystalline wax type). *(Ahmed Hammami et al., 1999*)

- Operating Temperature

Crude oil is a complex mixture of hydrocarbons that contain different functional groups such as paraffins, aromatics, naphthenes, resins, and asphaltenes. At reservoir temperatures, typically 70°C to 150°C, the solubility of these high-molecular-weight components is sufficient to keep them dissolved in the mixture. However, once the crude oil leaves the reservoir, it begins to cool and the solubility decreases drastically. The waxy crude oil is known to form congregates of complex morphology at low temperatures due to the formation of crystalline wax. *(Peter K.W. Herh et al., 2003)*

2.3 Paraffin Wax Deposition Problem

A major problem in oil extraction and line transporting is the build up of paraffin, restricting the flow. Production volumes are based on the amount of flow achieved through any given pipeline in a given amount of time. *(Enertec Inc., 1992)*

The presence of crystallised wax in a crude oil (or condensate) has a number of major impacts on the behaviour of the hydrocarbon phase in any flow line or process system:

- Crude behaviour changes from a predictable Newtonian to complex non-Newtonian fluid where flow properties which can affect pipeline operations are difficult to measure and predict.
- Wax may deposit within the pipeline leading to a reduction in diameter and achievable throughput. Deposition can be localised and in extreme circumstances lead to complete line blockage.
- Sufficient wax may crystallise in a specific orientation to lead to gelation of the crude should flow be terminated for any reason. The gel structure may be too strong to allow flow to re-start in the line without a physical intervention and the field production can be lost.
- Wax crystals can lead to the formation of stabilised emulsions within the flow line and in co-precipitation with asphaltenes produce complex emulsified hydrates which can result in flow line blockage.

It is important to realise that at some critical temperature any hydrocarbon containing high molecular weight (+C20) structures will exhibit the above properties. *(David Brankling, 1995)*

The properties of the waxy-gels formed under quiescent conditions have practical significance especially in the case of restart processes after the shutdown of processing and transportation units. *(Jose' A. Lopes da Silva et al., 2004)*

Crude oil may congeal on the walls of tankers, resulting in stock loss, and if it congeals in a pipeline, the required restart pressure may exceed the burst pressure of the line. Wax may precipitate out of solution and stick to pipe walls or form sludge at the bottom of a storage tank, even in warm climates. This wax deposition can block flow lines, reduce throughput, clog pumps, and inhibit the performance of metering devices that measure transferred crude oil. The pressure required to start the flow of a pipeline or the temperature at which the oil crystallizes depends greatly on its temperature history. *(Peter K.W. Herh et al., 2003)*

Wax precipitation and deposition occurring due to oil cooling during production, transportation, and storage of crudes cause detrimental effects in several aspects of crude oil processing. Accumulation of these solids in transport pipes and process equipment is an old and expensive problem in the petroleum industry. A vital step towards treating this problem is to be able to measure and possibly predict the equilibrium solid-liquid phase boundary (also known as the cloud point locus) as well as the amount of wax deposited under typical process conditions *(Hammami and Mehrotra, 1992)*. The rheological behavior of waxy oils is thus considered to be of crucial importance in the design of a pipeline, fuel cracking units, and for remediation purposes.

2.4 Magnetic Field

The efficacy of the treatment of fluids using magnetic fields is determined by the strength of the applicable magnetic field, the frequency associated with the field, the strength of the magnetic fields, and possible pulsation characteristic *(Charles F.Alcocer, 1997)*. Magnetic lines are one of the approaches to visualize the magnetic field. When drawn, the distance between the lines is an indication of the strength of the field. The closer the lines lead to the stronger the field. For example, the number of lines per square centimeter is a measure of the strength of the magnetic field. Specifically, 1 Gauss is equivalent to 1 magnetic field line within 1 square centimeter.

Magnetic lines have a number of important properties, which include:

i) all lines seek the path of least resistance between opposite magnetic poles,
ii) all lines never cross one another,
iii) all lines have the same strength,

iv) density decreases moving from area of higher permeability to lower permeability area, and

v) density decreases with increasing distance from the poles.

The magnetic field exerts force on a moving charge when the charge moves in a magnetic field. The magnitude of the force experienced by this particle is given by the following:

$$F = q\,v\,B\sin\theta \quad \text{(Newton, N)} \qquad [1]$$

The equation shows that the magnetic force depends on:

i) the charge of the particle, q

ii) the speed of the particle, v

iii) the magnitude of the magnetic field, B, and

iv) the magnitude of the angle between the velocity vector and the magnetic field vector, θ

where when $\theta = 0°$, the force vanishes and when $\theta = 90°$, the maximum force is experienced. Therefore, to achieve maximum magnetic force is by creating magnetic field lines at right angle when two similar magnets brought near to each other.

The electronic charge distribution changes dramatically with increasing field strength. The arrangement of the charge distribution leads to new binding properties for a certain class of electronic states. It has been found that for the parallel configuration, i.e. for parallel inter-nuclear and magnetic field axis, two distinct series of electronic states (with purely repulsive potential energy curves in the absences of the magnetic field) develop a minimum in the potential energy whose depth is increasing monotonically with increasing field strength. In short: a magnetic field induced binding mechanism has been observed *(U. Kappes and P. Schmelcher, 1995)*.

The changes of the electronic structure depend strongly on the orientation of the inter-nuclear axis with respect to the magnetic field: the angle, θ between the magnetic field and the inter-nuclear axis plays a major role here *(U. Wille, 1988; U. Kappes and P. Schmelcher, 1995)*. For field-free space it is a purely rotational degree of freedom whereas it acquires increasingly vibrational character with increasing field strength. This leads to hindered rotation of the molecule around the inter-nuclear axis. For weak fields P. Schmelcher and L.S. Cederbaum encounter a slightly perturbed rotational motion with respect to θ whereas with increasingly field strength the barrier for rotation grows and they observe strongly hindered rotational motion, rotational motion via tunneling and almost pure vibrational motion. For the different nuclear configurations the corresponding electronic wave functions exhibit significantly different properties.

2.4.1 Magneto-hydrodynamics

Magnetic fields induce currents in a moving conductive fluid, which create forces on the fluid and also change the magnetic field itself *(Baylor University Magnetic Group, 1984)*. Lorentz force is the force experiences by a charged particle at right angle to its direction of travel as it passes through a magnetic field.

The Lorentz force is given by the equation below:

$$F = q\,(E + v \times B) \qquad [2]$$

The equation shows that the magnetic force also depends on the charge of the particle, q, the electric field, E, the speed of the particle, v, and the magnitude of the magnetic field, B.

The principle of magneto hydrodynamics is that the magnetic fields can induce currents in a moving conductive fluid, which create forces on the fluid and also change the magnetic field itself. Voltage is produced when the fluid containing dissolved ions flow through a magnetic field. Denser the magnetic flux, the more current flowed and the measured voltage was a linear function of solution flow rate. The magnetic flux and flow rate affects the magnitude of voltages produced from a flowing fluid with charged particles, which correspond to electric field.

2.4.2 Theoretical Discussion on Magnetic Fluid Conditioners

The following mathematical relation is based on the work of Marques et al. (1997). Every work done on or by a system can be related to a change in its boundary (PdV), where the internal energy of the system (U) can be expressed in terms of the system entropy, volume and amount of moles of each of its components, as

$$U = TdS - PdV \quad [3]$$

where T = Temperature (K), S = Entropy (J/K), P = Pressure (bar) and V = Volume (m^3).

The work to magnetize a specific component is one of the types of work that may affect the system. Model and Reid (1974) derived an expression for the work done by magnetic field on a given component of a thermodynamic system as follows:

$$W = Vs\,\mu_o \int_0^M HdM \quad [4]$$

$$M = \left(\frac{\mu}{\mu_o} - 1\right) H \quad [5]$$

where V = Volume of system (m^3), μ_o = Free space magnetic permeability (H/m), M = Magnetization (A/m), H = Magnetic field strength (A/m) and μ = Actual substance magnetic permeability (H/m).

The actual material magnetic permeability (μ) is a function of material, pressure, temperature, and magnetic field strength. Adding equation [4] to fundamental equation of internal energy of a system [3], the following equation can be derived:

$$U = TdS - PdV + V_s\mu_o\,HdM + \square_J\mu_o\,dN_j \quad [6]$$

Equation [6] shows that the application of magnetic field on a given thermodynamic system can affect the crystallization temperature which will later affect the wax deposition process. Experiments carried out by Rocha (1997) with paraffins in organic solvents confirm the claim.

Mag-Well, Inc has come out with the scope of design for magnetic fluid conditioner. The scope of the design by comprises mane parameters being the following the most relevant:

i) Flux density, direction and strength of the magnetic field.

ii) Magnetic fluid conditioner internal velocity of the fluid being treated.

iii) Exposure time of the fluid to the magnetic flux of the magnetic fluid conditioner.

Which this indicate that the effect of a magnetic fluid conditioner to paraffin wax is rely on the parameters mentioned above.

2.5 Paraffin Wax under Magnetic Field

A characteristic of rheological fluids is that, when they are exposed to the appropriate energy field, solid particles in the fluid move into alignment and the ability of the fluid to flow is substantially decreased. *(Emil M. Shtarkman, 1992)*

The basic mechanism of the strong magnetic paraffin inhibition is that, when the crude oil flowed through the magnetizer, the wax (itself without magnetic torque) was set on the action of magnetic field and an electronic circumflex was generated in the molecule of wax and then a cyclic magnetic field was generated in the electronic circumflex. It disturbed and destroyed the orientation of the momentary magnetic pole in the wax molecule and weakened the chromatic dispersion force during the crystallization process of wax molecules such as to inhibit the growing and coagulation of wax crystals and to prevent the paraffin precipitation in oil wells. *(Wang Biao and Dong Lijian, 1995)*

When crude is flowed in an adequate magnetic field paraffin molecules tend to align their poles with the ones of the magnetic field as far as thermal agitation is not excessive. Moreover, the action of magnetic field on these molecules changes both electron rotation and translation patterns thus changing their orbital angular momentum. This leads to a disturbance in the crystal agglomeration processes. As the result, under a given magnetic field, weak dipoles are actually brought into being in the paraffin molecules. These dipoles generate a repulsion force between these molecules leading to changes in their rheological and morphological properties. *(Marques L.C.C. et al., 1997)*

Several attempts have been made to use permanent magnet devices to reduce downhole build up. Examples of several of the attempts include U.S Pat. No. 3228878 which is issued to Moody on Jan. 11, 1966 and discloses the use of magnets to provide a magnetic field having two polar zones a short distance from each other. The field may be provided by one or more high strength permanent magnets located outside the flow passageway and each having its poles facing toward the passageway in a direction normal to its path of flow. The magnetically treated liquid may flow with a minimum of turbulence and free it from external magnetic influence for a distance within the flow passageway from 10 to 150 times the length of the magnetic field to avoid too rapid a dissipation of the change effected therein by the passage through the magnetic field. *(Terence Borst et al., 2008)*

As a further example, U.S. Pat. No. 5178757 to Mag-Well, Inc. describes a device that includes an elongated hollow core providing at least one passage through which the fluid to be treated flows. An array of magnets extends longitudinally along the core with the poles of the magnets arranged so as to provide a magnetic field perpendicular to the flow path to enhance the magnetic field perpendicular to the flow path to enhance the magnetic conditioning effect of the tool. An alternative embodiment of the device has three longitudinally extending arrays of magnets with two fluid passages between them. The magnets are formed of a rare earth magnetic material, and are backed by a flux-carrying member of cobalt-iron alloy, with rounded corners so as to reduce loss of a magnetic field. Each magnet is mounted at least partially within an outer surface of the core with the flux-carrying member contacting, covering, and extending between the outer major faces of the magnets.

Faraday's law of electrolysis states that "The mass of substance deposited or liberated from a solution is directly proportional to the quantity of charge which flows through the circuit." The magnetic fluid conditioner alters the electrical potential of crude, which change the nature and retards and reduces deposition of paraffin. Crude oil, when flowing through sand and production lines, produces an electrical potential. As it passes through the monopole magnetic fields, the crude's potential is altered causing its, chemical, mechanical and electrical properties to change. This eliminates the crystal process at the thermal of cloud point and the transformation of paraffin from a liquid to a solid-state ceases. This reduces the surface tension and the viscosity of the crude. By controlling the surface tension of the crude, the paraffins are kept in solution rather than adhering to each other and sticking of the tubing. *(Mundimex Inc., 2003)*

Oil, like water and other fluids, has a molecular structure which can be altered when exposed to an induction field. When the fluid stabilization system is placed above ground, on the discharge of the well head, the fluid polarization has a reversing effect on the incoming oil from the well. These forces realign the molecules within the carbon steel, as well as the oil, creating a molecular chain the entire length of the casing. This force is sufficient to keep the paraffin molecules in solution (suspension). *(Enertec Inc., 1992)*

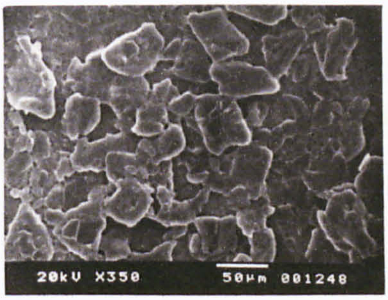


Figure 2.7: Pure Paraffin Crystal Morphology

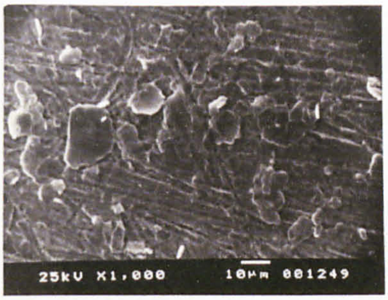


Figure 2.8: Pure Paraffin Crystal Morphology Magnetically Treated

(Nguyen Phuong Tung et al., 2001)

The changes in wax crystal morphology are observed in the figure above. The changes in shape and size, and water wetting layers allowed paraffin crystals sliding faster in the flow without flocculating and enhancing surrounding walls of flowlines and pipelines. All these result in sharply viscosity and wax deposition reducing. These Scanning Electronic Microscopy (SEM) pictures also showed the obtained long-lasting effect of magnetic treatment. The SEM picture of untreated paraffin deposit showed the crystal appearance in very large, thin-blade forms of 50µm size. The paraffin crystals obtained from treated paraffin solution have showed, under SEM, in much smaller (5-10µm) size and rounder forms. This can be explained like Rocha cited before. *(Nguyen Phuong Tung et al., 2001)*

2.6 Paraffin Wax Deposit Test

A test has been conducted in Lab test at Lucas Fuel Systems, Acton, England to study on paraffin wax deposit removal. In the test to measure the effect of magnetic field on paraffin wax deposits, the temperature of the crude oil is maintained at 53°C, the cooling water temperature at 10°C, and the period of time that the water circulates at 30 minutes. The weight of the paraffin wax deposits were measured on a wax content meter. Then, the strength of the magnetic field was increased to 1200

Gauss, and the weight of the paraffin wax deposits was measured under the same conditions. The results of measurement indicated that in 282 gm oil, as a result of using a magnetic field, it was possible to reduce the paraffin wax deposits by 12.3%.

2.7 Application of Surface Unit

Recommended placements for magnetic fluid conditioner (surface unit) are stated below:

- Installation on production line

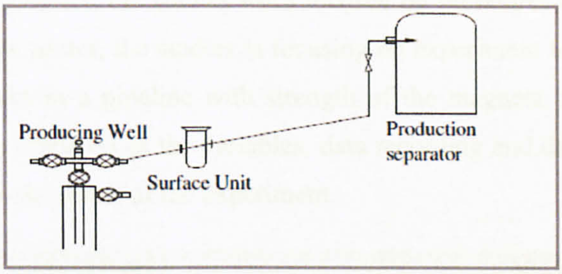


Figure 2.9: Surface Unit on Production Line

- Installation on production battery

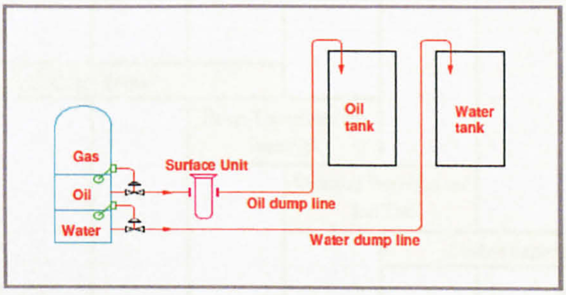


Figure 2.10: Surface Unit on Production Battery

- Installation at oil transfer station

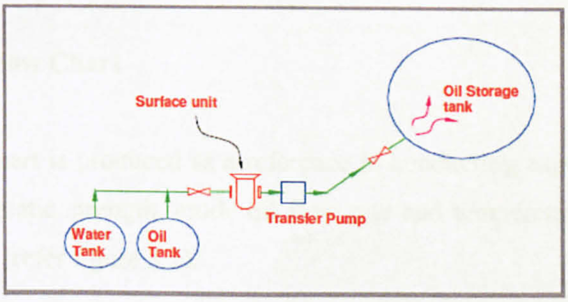


Figure 2.11: Surface Unit at Oil Transfer Station

(Lotus Heights Sdn Bhd, 2003)

CHAPTER 3
METHODOLOGY

3.1 Project Milestone

This project milestone consists of six chapters which three chapters for last semester (semester January 2009) and the remaining three chapters for this semester (semester July 2009). Last semester, the studies were focused on literatures and designing the experiment. This semester, the studies is focusing on experiment to test the removal rate of paraffin wax in a pipeline with strength of the magnets, flow rate and the temperature of the crude oil as the variables, data recording and data analysis of the obtained data from the result of the experiment.

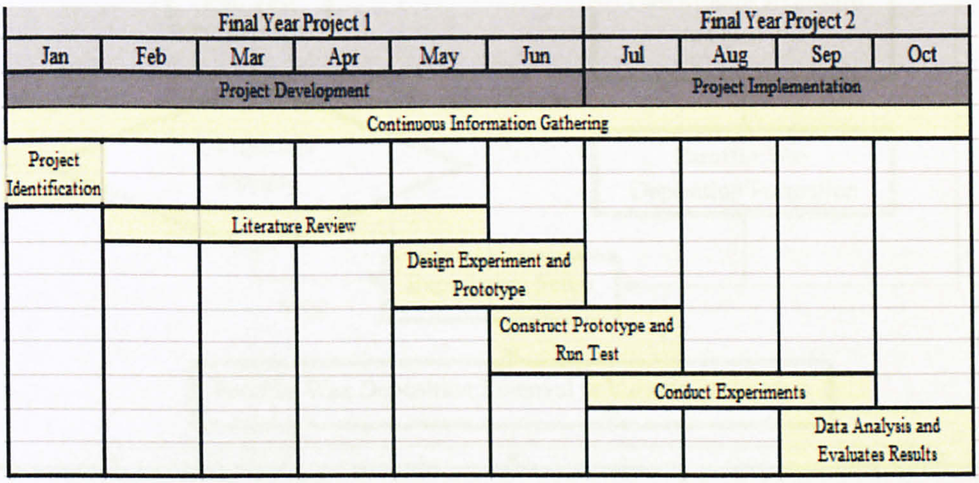


Figure 3.1: Final Year Project Milestone

3.2 Process Flow Chart

A process flow chart is produced as a reference in conducting experiments to study the effect of magnetic strength, crude oil flow rate and temperature to the paraffin wax removal rate (refer figure 3.2).

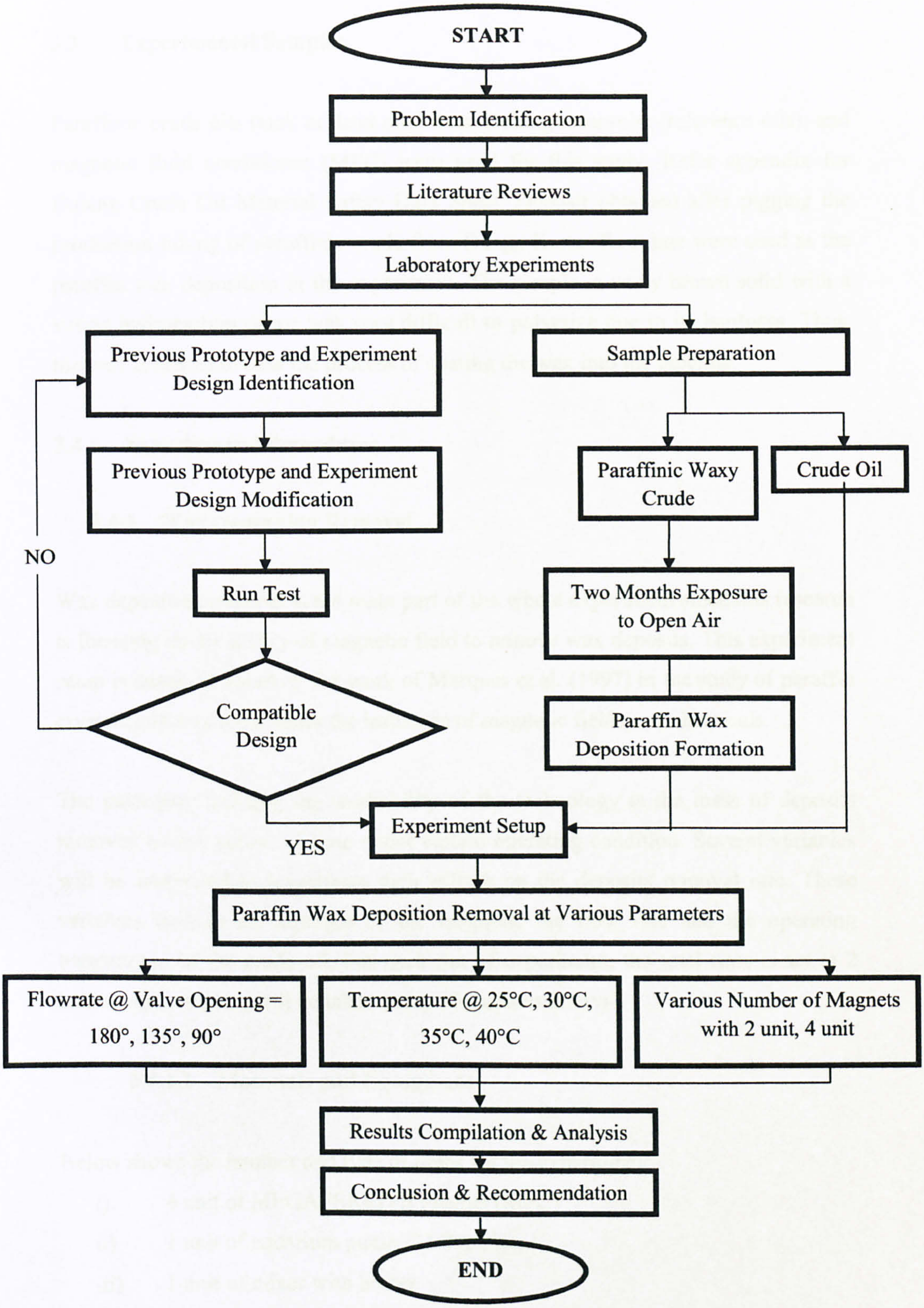


Figure 3.2: Final Year Project Process Flow Chart.

3.3 Experimental Samples

Paraffinic crude oils (tank or dead oils) from Dulang reservoirs (reference oils), and magnetic fluid conditioner (MFC) were used for this study. Refer appendix for Dulang Crude Oil Material Safety Data Sheet. Deposit obtained after pigging the production tubing of paraffinic crude from Bunga Kertas flow line were used as the paraffin wax deposition in the experiment. The sample, a waxy brown solid with a strong hydrocarbon odour was very difficult to pulverize due to its hardness. Thus, the wax is heated to ease the process of coating the wax into the pipeline.

3.4 Experimental Procedures

3.4.1 Wax Deposition Removal

Wax deposition removal is the main part of the whole experiment since this research is focusing on the ability of magnetic field to remove wax deposits. This experiment setup is designed based on the work of Marques et al. (1997) in the study of paraffin crystallization process under the influence of magnetic fields and chemicals.

The parameter defining the workability of the technology is the mass of deposits removed over a period of time under certain operating condition. Several variables will be integrated to investigate their effects on the deposits removal rate. These variables include the strength of the magnets, the flow rate and the operating temperature of the crude oil. For each run of experiment, the total time is set at 2 hours where reading will be taken every 15 minutes interval.

3.4.1.1 Materials and Equipment

Below shows the number and type of items for the experiment:

i) 4 unit of MEGAFERRITE magnet (MFC)
ii) 1 unit of aquarium pump (25 W)
iii) 1 unit of mixer with heater
iv) 1 unit of plastic container
v) 2' of ¾" Galvanized Iron (GI) pipe

vi) 8' of ¾" PVC pipe
vii) 1 unit of ¾" globe valve
viii) 1 unit of weighting scale
ix) 1 unit of magnetometer
x) 20 liter of crude oil
xi) 1kg of paraffin wax deposition

3.4.1.2 Experiment Procedure

Following steps describe the procedures to measure the flow rate:

i) Experiment was setup base on Figure 3.4.
ii) The experiment was run and allowed to stabilize a few minutes.
iii) A measuring cylinder was placed at the end of the flow loop.
iv) The stopwatch was started simultaneously.
v) The measuring cylinder was removed from the pipe outflow before fully filled.
vi) The stopwatch was stopped simultaneously.
vii) The volume of crude oil in cylinder and the time taken was recorded.
viii) The volume was divided with time to obtain the flow rate.
ix) Step i to step viii was repeated for 2 times to get better accuracy.
x) The final value was determined from the average of all 6 readings.

Following steps describe the procedure to measure the strength of the magnet:

i) A magnetometer was turned on by pressing the 'ON' button.
ii) Meter probe was placed at right angle to magnet at point 1 (refer figure 3.3).
iii) Range of reading was attuned as necessary.
iv) Measurement was taken 3 times after reading stabilized.
v) Step ii to iv were repeated for point 2 to 12.
vi) Data obtained was recorded.
vii) Step v and vi is taken for all experiment with different operating conditions.

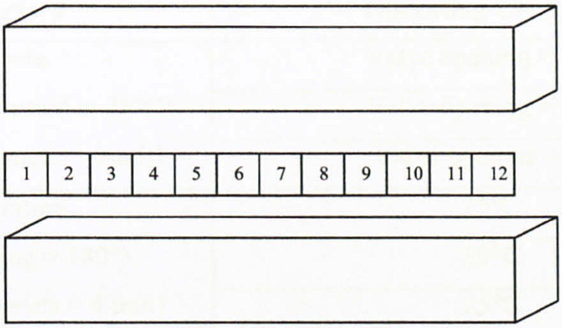


Figure 3.3: Measurement Points

Following steps describe the procedures to measure the amount of paraffin wax removed:

i) Pipe A and B were weighed and the values are recorded.

ii) Pipe A and B were conditioned by allowing the paraffinic crude to solidify in 24 hours.

iii) The pipes were attached to the setup.

iv) Then container was filled with 20liter of crude oil.

v) MFC was mounted on Pipe A.

vi) The ball valve was opened fully.

vii) The pump was started and circulated for 15 minutes.

viii) The pump was stopped and the MFC was detached from the pipes.

ix) Both pipes were weighed and the values were recorded.

x) The amount of removed paraffin was calculated.

xi) Step i to x was repeated for total 2 hours according to Table 3.1.

Table 3.1: Variable Parameters

Parameters	**Operating Condition**
Flow rate (Temperature constant at 25°C) (Number of magnets = 4 unit)	Valve opening = 180°
	Valve opening = 135°
	Valve opening = 90°
Temperature (Valve opening = 180°) (Number of magnets = 4 unit)	25°C
	30°C
	35°C
	40°C
Number of magnets (Temperature constant at 25°C) (Valve opening = 180°)	2 unit
	4 unit

3.4.1.3 Experiment Setup

The whole flow loop is constructed from PVC pipes except for Pipe A and B which are made from GI pipes. MFC is mounted on Pipe A in a configuration where south pole of the top magnet is facing downward while the north pole of the bottom magnet is facing upward (refer figure 3.3).

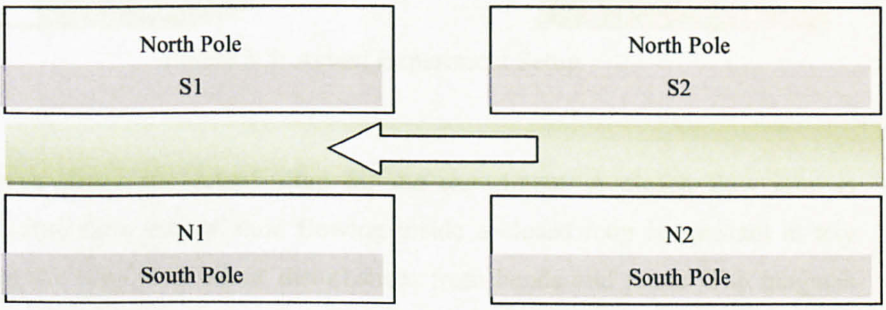


Figure 3.4: Magnets Arrangement

Hence, theoretically no line is expected at the area between both magnets at the top portion or bottom. Lines will only be crossing along the length of magnets between the top magnet and the bottom magnet which are of different poles. The actual result is indeed in accord with the theoretical image where all the lines were at right angle to direction of flow along the length of pipe. *(Chai Set Lee, 2008)*

For experiment with 2 units of magnets, the number of 4 magnets is reduced to 2 units with the same arrangement where the south pole of the top magnet is faced down while the north of the bottom magnet is face up. However, for the measurement of the magnetic flux density, the average from the combination of S1 and N1 pair and S2 and N2 pair is taken for precise value. The aquarium pump is placed inside the container with cotton filter at the suction part of pump to prevent the paraffin wax deposition from entering the pump. The whole structure is supported by mild steel put together using bolts and nuts.

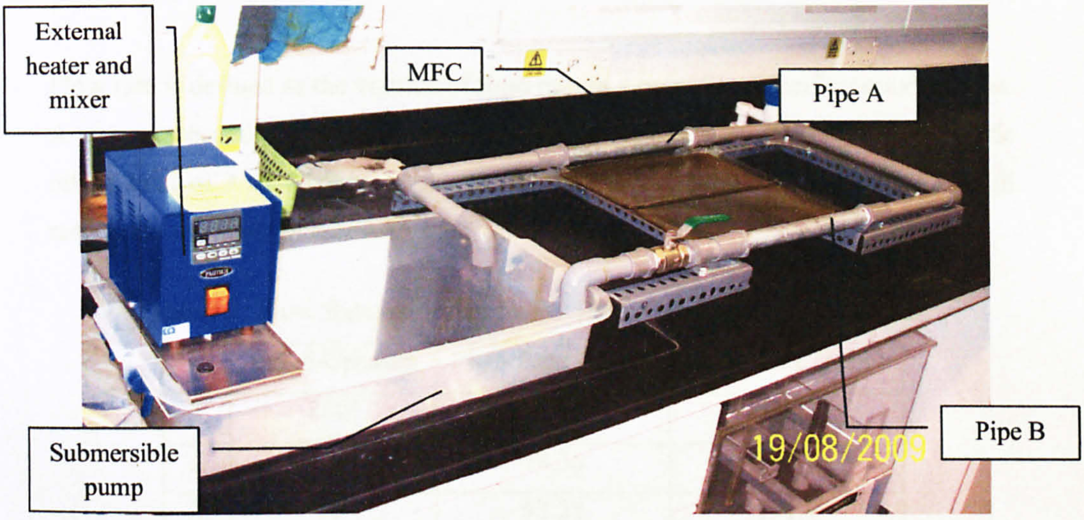


Figure 3.5: Actual Experiment Setup

Figure above shows the actual setup for the experiment. A closed flow loop is chosen because flow rate of fluid flowing inside a closed loop is constant at any point along the loop with minor disturbances from bends and joints. The magnets (MFC) are placed on the opposite side of the pump in order to let fluid to stabilize and achieve constant rate in order to eliminate any possible effect of turbulence and high flow rate on wax removal. External heater and mixer are used to supply heat to the fluid and to ensure the crude oil condition and composition is constant throughout the experiment. The experiment is design to get the result within small time interval. Thus, the strength of the magnet, the flow rate and the temperature of the crude oil set in the experiment is not base on industrial operating condition.

CHAPTER 4

RESULTS AND DISCUSSION

Accurate recording of results is very important in order to depict reliable conclusions and provide relevant recommendations. Thus, all outcome obtained from the experiments were gathered precisely and graphically displayed. Deep analyses were performed and associated discussions were generated.

4.1 Flow Rate

Flow rate is defined as the volume of fluid passes a point in a specific period of time. A stop watch and a 100 ml cylinder are used to measure the flow rate of the crude oil. A total of 3 readings were taken and the average will be the final value. Full results are available in appendix section.

Table 4.1: Flow Rate for Valve Fully, Three Quarter and Half Opened

No.	Valve Opening	Flow Rate (mL/s)	Flow Rate (L/hr)
1	180°	103.38	372.2
2	135°	78.36	282.1
3	90°	53.31	191.9

Table 4.1 shows that valve with full opening has the highest crude oil flow rate. Three quarter valve opening resulted in flow rate value three quarter than the value of fully opened valve. Same goes to half opened valve where the crude oil flow rate is half of the fully opened valve value. The pump operated at 372.2L/hr which is lower than the designed capacity indicated in the operating manual, 1500 L/hr. The pump not performing at its optimum capacity during the experiment might due to the paraffinic crude oil viscosity. In addition, the accuracy of the results can be indefinite due to human error where response time between taking the crude oil volume and stopping the stopwatch will in some way affect the readings taken.

4.2 Magnetic Flux Density

Magnetometer is used to measure the magnetic flux density where the unit is in mili Tesla. This equipment operates on Halls Effect principle. North pole will give a positive values while south pole will give a negative value. All conditions with different parameters were assessed for magnetic flux density.

Readings were taken at 12 points on the pipe between the magnets after crude oil starts circulating in the flow loop. Each reading was taken three times for each point to obtain precise value. The average of the twelve values is the magnetic flux density for one magnet. Therefore, the averages of all magnets will be taken as the final value for a magnetic flux density.

4.2.1 Sample Results for Valve Fully Opened at 25°C with 4 Unit Magnets

Table 4.2: Pair S1 and N1

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-16	-16	-16	16.00
2	-15	-16	-17	16.00
3	-15	-19	-18	17.33
4	-15	-16	-20	17.00
5	-18	-17	-21	18.67
6	-14	-18	-19	17.00
7	-19	-16	-20	18.33
8	-18	-17	-22	19.00
9	-12	-18	-20	16.67
10	-19	-18	-23	20.00
11	-15	-18	-20	17.67
12	-16	-20	-21	19.00
				Σ = 212.67

Mean of Average Value = 212.67 / 12

= 17.72

Magnetic Flux Density for Pair S1 and N1 = 17.72mT

Table 4.3: Pair S2 and N2

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-14	-13	-13	13.33
2	-16	-16	-16	16.00
3	-13	-11	-13	12.33
4	-15	-16	-15	15.33
5	-12	-12	-11	11.67
6	-15	-15	-15	15.00
7	-15	-14	-14	14.33
8	-11	-12	-12	11.67
9	-14	-14	-15	14.33
10	-12	-13	-15	13.33
11	-12	-11	-13	12.00
12	-10	-12	-12	11.33
				Σ = 160.65

Mean of Average Value = 160.65 / 12

= 13.39

Magnetic Flux Density for Pair S2 and N2 = 13.39 mT

The magnetic flux density when the valve is fully opened at 25°C is the average value of flux density for both pair S1 & N1 and S2 & N2 which is 15.56mT. Refer appendix for other results.

4.2.2 Magnetic Flux Density for All Operating Conditions

Table 4.4: Summary of Magnetic Flux Density

Parameters	Operating Condition	Flux Density (m Tesla)
Flow rate (T= 25°C, 4 unit magnets)	Valve opening = 180°	15.56
	Valve opening = 135°	14.99
	Valve opening = 90°	14.74
Temperature (Fully opened valve, 4 unit magnets)	25°C	15.56
	30°C	14.88
	35°C	14.96
	40°C	14.99
Number of magnets (T= 25°C, fully opened valve)	2 unit	7.535
	4 unit	15.56

The values of magnetic flux density for all operating conditions selected for the experiment is shown in table above. It seems that when 4 magnets with the ball valve fully opened will give the highest flux density at 15.56 m Tesla. This value is closely followed behind by operating condition with the three quarter opened valve at 14.99 m Tesla. The percentage difference between these two values is 3.7%. This small difference is might due to the fact that the fluid flow rate does not affect much the flux density which depends totally on the magnets strength. The same goes to the condition of different temperature where the flux density is slightly the same. However, the flux density for 2 unit of magnets is half of the 4 unit of magnets value. This prove that the flux density depend on the number of magnets which indicates the strength of the magnets.

4.3 Wax Deposition Removal

Through previous experiments on magnetic field lines and flow rate, seven conditions have been identified and tested in the wax deposition removal experiment. For each condition, a total time of 2 hours was allocated with readings taken between

15 minutes interval. In order to get more precise results, each reading was taken 3 times and the final value is the average.

A weighing scale with sensitivity up to 3 decimal points was used to get accurate reading. All values recorded are presented in table form available in Appendix section. Using these values, graphical representations are generated to highlight visible pattern changes through the graphs.

4.3.1 Sample Results for Valve Fully Opened at 25°C with 4 Unit Magnets

Table 4.5: Summary of Mass for Pipes

	Pipe A (g)	Pipe B (g)
Initial mass of pipe without wax	517.00	523.00
Initial mass of pipe with wax	559.42	565.99
Final mass of pipe with wax	519.85	525.86

Table 4.6: Mass of Pipes over Time

Time (Hour)	Pipe A (g)	Pipe B (g)
0.00	559.42	565.99
0.25	523.29	533.39
0.50	520.86	527.83
0.75	519.97	526.45
1.00	519.85	525.86
1.25	519.85	525.86
1.50	519.85	525.86
1.75	519.85	525.86
2.00	519.85	525.86

The mass of wax can be calculated from the data obtained in Table 4.5 and 4.6. The mass of wax is the difference between the values of mass of pipe with wax and the initial mass of pipe without wax.

Table 4.7: Percentage of Wax Removed over Time

Time (Hour)	Pipe A (%)	Pipe B (%)
0.00	0.00	0.00
0.25	85.17	74.11
0.50	90.90	86.75
0.75	93.00	89.88
1.00	93.28	91.23
1.25	93.20	91.20
1.50	93.21	91.21
1.75	93.18	91.19
2.00	93.17	91.17

4.3.2 Results for All Operating Conditions

Results for all operating conditions are presented graphically to get clear view on the effect of the different operating conditions to paraffin wax deposition removal.

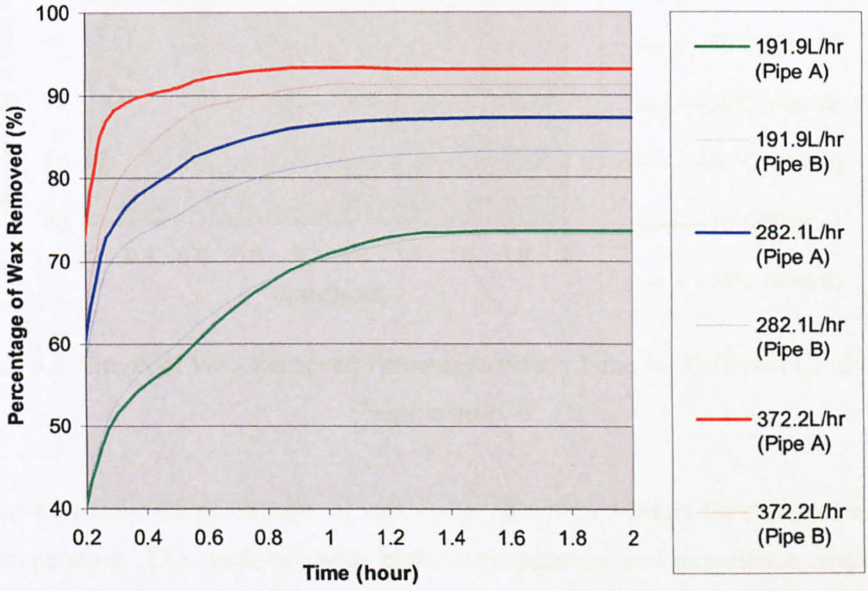


Figure 4.1: Graph of Wax Removed Percentage versus Time for Different Crude Oil Flow Rate

Figure 4.1 represents the percentage of wax removed for different flow rate of crude oil in 2 hours. In this experiment, the flow rate of the crude oil is varies by varying the valve opening. The larger the opening of the valve indicates the higher the flow rate of the crude oil. The pipe attached with magnet and experience highest flow rate has the highest wax removal rate where 93.17% of the wax is removed within 2 hours. And this followed with the pipe with the same flow rate without magnet where 91.17% of the wax is removed within 2 hours. This shows that the existence of the magnetic field increased the wax removal rate by 2%. It is observed that the pipe without magnet with lowest flow rate has the lowest removal rate where 73.25% of the wax is removed within 2 hours. The removal rate at the pipe with magnet and same flow rate is higher where 73.5% wax is removed in 2 hours. However, with the existence of magnetic field, the removal rate increases by 0.25%. This indicates that the flow rate of the crude oil affected the performance of the magnet in wax removal.

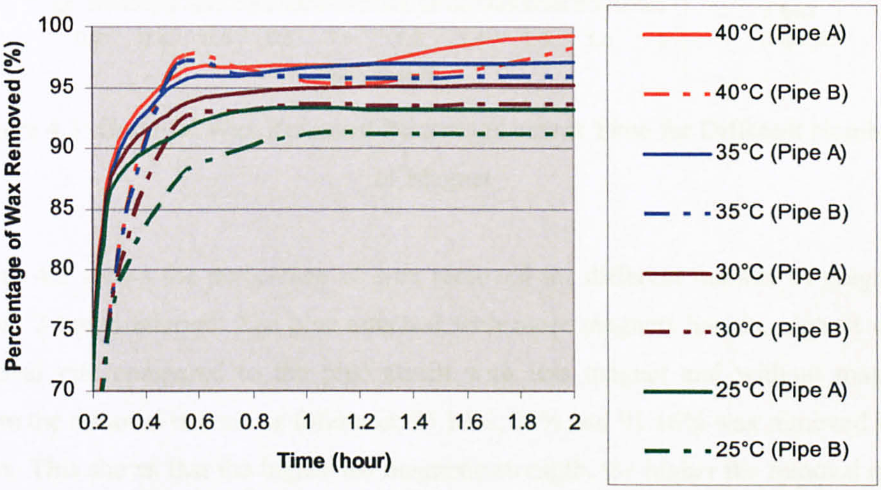


Figure 4.2: Graph of Wax Removed Percentage versus Time for Different Crude Oil Temperature

Figure 4.2 shows the percentage of wax removed within 2 hours for different crude oil temperature. The crude oil with highest temperature and experience magnetic field has the highest removal rate where 99.31% of the wax is removed within 2 hours duration. And this followed with crude oil with the same temperature but without experiencing magnetic field where 98.24% of paraffin wax is removed within the same duration. It is also observed that when the temperature is lowered, the removal rate is lower. At lowest temperature and without magnetic field exposure, the wax removed percentage is the lowest, 91.17%. At the same temperature with magnetic field exposure, the wax removed percentage is 93.17%. This also indicates that the paraffin wax removal is also affected by the temperature of the crude. In addition, with the existence of the magnet, the removal rate is higher in the first 30 minutes compared to after 30 minutes.

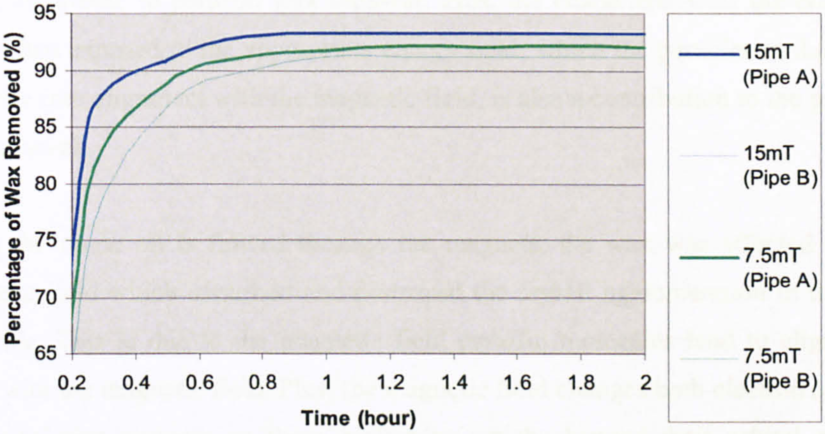


Figure 4.3: Graph of Wax Removed Percentage versus Time for Different Number of Magnet

Figure 4.3 shows the percentage of wax removed for different number of magnets within 2 hours interval. The pipe attached with more magnets has the highest wax removal rate compared to the pipe attach with less magnet and without magnet where the removal rate are as followed; 93.17%, 92% and 91.16% wax removed in 2 hours. This shows that the higher the magnetic strength, the higher the removal rate. However since we have constraint with the number of magnets, it is hard to predict whether with more number of magnet will give the same result or not. It is proposed in the future experiment to use electromagnet so that it is easy to vary the strength of the magnet. This is because the more the parameter, the more accurate the result will be obtained.

CHAPTER 5

CONCLUSION

From the compilation of literature review on the effect of magnetic field to the paraffin wax removal, it is proved that the magnetic field has its own characteristics which contribute to paraffin wax removal. Plus, the characteristic of the crude oil itself when exposed to the appropriate energy field, which the particles in the crude oil move into alignment with the magnetic field, is also a contribution to the paraffin wax removal.

When the crude oil is flowed through the magnets, the wax was affected by the magnetic field which disturbed and destroyed the crystal agglomeration in the wax molecule. This is due to the magnetic field paraffin molecules tend to align their poles with the magnetic field. Plus, the magnetic field changes both electron rotation and translation patterns on these molecules which changed their orbital angular momentum. As a result, weak dipoles are brought into the paraffin molecules which generate a repulsion force between these molecules.

The magnetic field also alters the electrical potential of crude which was produced during the crude flow. This causes the surface tension of the paraffin wax to reduce which will transform it into solution rather than adhering to each other and stick to the pipe.

It was said about the magnetic effect on wax deposition reducing, but as we have observed, without giving any experimental data. To better to find out how magnetic fields affect the paraffin wax deposition removal, experiments with a deposition cell were setup and results were showed. As it was explained in the results and discussion, under the magnetic treatment, the reduction of wax deposition for all tested samples was about 73-100% depends on the operating conditions designed. These results however does not totally indicate the real situation in the industry since the paraffin wax used in the experiment has different stiffness compared to the one in industry.

However, base on these results, a big advantage in energy economy can be obtained, where here, it has been proven the effectiveness of using magnetic field to reduce paraffin wax deposition which cause problem to the industry in terms of cost and production. The efficiency of the magnetic field can be improved with some modification to the magnet strength, the crude oil flow rate and temperature. Results from this study hopefully will have significant impact in the industry to solve problems in crude oil production and transportation. This new investigation is proposed to be advance studied on the effect of magnetic field which could produce precise scientific explanation on the whole process.

CHAPTER 6

RECOMMENDATION

Due to certain obstacles faced throughout completing this project, there are some results obtained which does not reach their target. Thus some recommendation has been made base on the problem faced in order to improve the project in advance:

1. Materials

   The samples used in the experiment are paraffinic crude oil and paraffin wax deposition which contained some hazardous materials. A proper planning in handling the housekeeping after the experiment is required to avoid misspend time and proper material handling and workspace is needed to avoid unexpected accident. Lab coat, hand glove, goggle and mask must be worn all the time conducting the experiment and performing housekeeping. It is also suggested to conduct the experiment in adequate workstation as the samples might harm others within the area.

2. MFC

   The effectiveness of MFC depends on the strength of the magnets, the crude oil flow rate and temperature. Since the prototype designed is experimental lab basis, some modification is needed to fit it with the industrial requirement.

3. Equipment

   It is suggested to use equipment with high technology to get more scientific data such as the gel permeation chromatography to analyze molecular weight distribution, gas chromatography to analyze carbon number distribution of wax and nuclear magnetic resonance to analyze branch degree in wax structure. A measurement of surface tension is also needed to prove whether the magnetic field has attribution to reduce the surface tension of the paraffin wax deposition. And also, to get more accurate data, it is proposed to use machine in most of the data recording since human handling might contribute to some error in recording.

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APPENDICES

Appendix 1: Flow Rate when Valve Fully Opened

No.	Volume of Water (mL)	Time (s)	Flow Rate (mL/s)	Flow Rate (L/hr)
1	88	0.8	110.00	396.00
2	88	0.9	97.78	352.00
3	83	0.8	103.80	373.50
4	90	0.9	100.00	360.00
5	91	0.9	101.10	364.00
6	86	0.8	107.50	387.00

Flow rate of liquid when valve fully opened = <u>372.2L/hr</u>

Appendix 2: Flow Rate when Valve Three Quarter Opened

No.	Volume of Water (mL)	Time (s)	Flow Rate (mL/s)	Flow Rate (L/hr)
1	86	1.0	86.00	309.60
2	94	1.2	78.33	282.00
3	93	1.3	71.54	257.54
4	92	1.1	83.64	301.09
5	93	1.3	71.54	257.54
6	95	1.2	79.17	285.00

Flow rate of liquid when valve three quarter opened = <u>282.1L/hr</u>

Appendix 3: Flow Rate when Valve Half Opened

No.	Volume of Water (mL)	Time (s)	Flow Rate (mL/s)	Flow Rate (L/hr)
1	82	1.7	48.24	173.65
2	97	1.7	57.06	205.41
3	95	1.8	52.78	190.00
4	92	1.7	54.12	194.82
5	92	1.8	51.11	184.00
6	96	1.7	56.47	203.29

Flow rate of liquid when valve half opened = <u>191.9L/hr</u>

Appendix 4: Magnetic Flux Density for Pair S1&N1
(Valve Half Opened at 25°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-13	-14	-15	14.00
2	-14	-14	-14	14.00
3	-13	-13	-14	13.33
4	-14	-13	-14	13.67
5	-14	-14	-15	14.33
6	-15	-13	-14	14.00
7	-15	-15	-15	15.00
8	-15	-15	-16	15.33
9	-14	-15	-14	14.33
10	-15	-16	-15	15.33
11	-16	-16	-16	16.00
12	-17	-18	-18	17.67

Magnetic Flux Density for Pair S2 and N2 = 14.75 mT

Appendix 5: Magnetic Flux Density for Pair S2&N2
(Valve Half Opened at 25°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-15	-14	-14	14.33
2	-14	-14	-14	14.00
3	-12	-13	-14	13.00
4	-14	-15	-14	14.33
5	-16	-15	-14	15.00
6	-14	-15	-14	14.33
7	-14	-17	-16	15.67
8	-14	-17	-16	15.67
9	-13	-14	-15	14.00
10	-14	-16	-15	15.00
11	-13	-15	-15	14.33
12	-16	-17	-18	17.00

Magnetic Flux Density for Pair S1 and N1 = 14.72 mT

Appendix 6: Magnetic Flux Density for Pair S1&N1
(Valve Three Quarter Opened at 25°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-14	-14	-15	14.33
2	-15	-14	-14	14.33
3	-14	-13	-14	13.67
4	-15	-13	-14	14.00
5	-14	-15	-15	14.67
6	-15	-14	-14	14.33
7	-15	-16	-15	15.33
8	-15	-15	-16	15.33
9	-14	-15	-15	14.67
10	-15	-16	-15	15.33
11	-16	-17	-17	16.67
12	-17	-18	-17	17.33

Magnetic Flux Density for Pair S1 and N1 = <u>15.00 mT</u>

Appendix 7: Magnetic Flux Density for Pair S2&N2
(Valve Three Quarter Opened at 25°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-16	-14	-15	15.00
2	-14	-15	-14	14.33
3	-13	-14	-14	13.67
4	-14	-15	-14	14.33
5	-16	-15	-14	15.00
6	-15	-16	-14	15.00
7	-15	-17	-16	16.00
8	-14	-17	-16	15.67
9	-13	-14	-15	14.00
10	-14	-16	-15	15.00
11	-13	-15	-15	14.33
12	-16	-18	-18	17.33

Magnetic Flux Density for Pair S2 and N2 = <u>14.97 mT</u>

Appendix 8: Magnetic Flux Density for Pair S1&N1

(Valve Full Opened at 30°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-14	-14	-16	14.67
2	-14	-14	-14	14.00
3	-13	-14	-15	14.00
4	-14	-14	-14	14.00
5	-14	-15	-15	14.67
6	-15	-14	-14	14.33
7	-15	-16	-15	15.33
8	-15	-15	-16	15.33
9	-14	-15	-15	14.67
10	-15	-15	-15	15.00
11	-16	-15	-16	15.67
12	-17	-18	-18	17.67

Magnetic Flux Density for Pair S1 and N1 = 14.94 mT

Appendix 9: Magnetic Flux Density for Pair S2&N2

(Valve Full Opened at 30°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-15	-15	-14	14.67
2	-14	-15	-14	14.33
3	-12	-14	-14	13.33
4	-14	-15	-14	14.33
5	-16	-15	-14	15.00
6	-14	-14	-14	14.00
7	-14	-16	-16	15.33
8	-14	-17	-16	15.67
9	-13	-15	-15	14.33
10	-14	-16	-15	15.00
11	-13	-16	-15	14.67
12	-16	-17	-18	17.00

Magnetic Flux Density for Pair S2 and N2 = 14.81mT

Appendix 10: Magnetic Flux Density for Pair S1&N1

(Valve Full Opened at 35°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-15	-16	-14	15.00
2	-14	-16	-15	15.00
3	-12	-13	-14	13.00
4	-15	-16	-14	15.00
5	-16	-15	-14	15.00
6	-15	-14	-14	14.33
7	-14	-16	-16	15.33
8	-14	-16	-16	15.33
9	-13	-16	-15	14.67
10	-14	-16	-16	15.33
11	-14	-16	-14	14.67
12	-17	-16	-18	17.00

Magnetic Flux Density for Pair S1 and N1 = 14.97 mT

Appendix 11: Magnetic Flux Density for Pair S2&N2

(Valve Full Opened at 35°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-13	-14	-15	14.00
2	-14	-15	-14	14.33
3	-13	-15	-15	14.33
4	-14	-15	-14	14.33
5	-14	-15	-15	14.67
6	-15	-15	-14	14.67
7	-15	-16	-15	15.33
8	-15	-16	-15	15.33
9	-14	-16	-15	15.00
10	-15	-14	-15	14.67
11	-15	-15	-16	15.33
12	-17	-17	-18	17.33

Magnetic Flux Density for Pair S2 and N2 = 14.94 mT

Appendix 12: Magnetic Flux Density for Pair S1&N1

(Valve Full Opened at 40°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-14	-14	-15	14.33
2	-14	-16	-14	14.67
3	-13	-14	-15	14.00
4	-14	-15	-15	14.67
5	-14	-15	-16	15.00
6	-15	-16	-14	15.00
7	-16	-16	-15	15.67
8	-15	-15	-15	15.00
9	-14	-15	-15	14.67
10	-15	-14	-15	14.67
11	-15	-15	-16	15.33
12	-17	-17	-18	17.33

Magnetic Flux Density for Pair S1 and N1 = 15.03 mT

Appendix 13: Magnetic Flux Density for Pair S2&N2

(Valve Full Opened at 40°C with 4 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-16	-15	-14	15.00
2	-14	-16	-15	15.00
3	-12	-14	-14	13.33
4	-15	-15	-14	14.67
5	-16	-16	-14	15.33
6	-15	-16	-14	15.00
7	-14	-16	-15	15.00
8	-14	-15	-16	15.00
9	-13	-14	-15	14.00
10	-14	-15	-16	15.00
11	-14	-16	-15	15.00
12	-17	-16	-18	17.00

Magnetic Flux Density for Pair S2 and N2 = 14.94 mT

Appendix 14: Magnetic Flux Density for Pair S1&N1

(Valve Full Opened at 25°C with 2 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-7.0	-7.0	-7.5	7.17
2	-7.0	-8.0	-7.0	7.33
3	-6.5	-7.0	-7.5	7.00
4	-7.0	-7.5	-7.5	7.33
5	-7.0	-7.5	-8.0	7.50
6	-7.5	-8.0	-7.0	7.50
7	-8.0	-8.0	-7.5	7.83
8	-7.5	-7.5	-7.5	7.50
9	-7.0	-7.5	-7.5	7.33
10	-7.5	-7.0	-7.5	7.33
11	-7.5	-7.5	-8.0	7.67
12	-8.5	-8.5	-9.0	8.67

Magnetic Flux Density for Pair S1 and N1 = 7.51 mT

Appendix 15: Magnetic Flux Density for Pair S2&N2

(Valve Full Opened at 25°C with 2 Unit Magnets)

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-8.0	-7.5	-7.5	7.67
2	-7.0	-8.0	-7.5	7.50
3	-6.0	-7.0	-7.0	6.67
4	-7.5	-8.0	-7.0	7.50
5	-8.0	-8.0	-7.0	7.67
6	-7.5	-8.0	-7.0	7.50
7	-7.0	-8.0	-7.5	7.50
8	-7.0	-7.5	-8.0	7.50
9	-6.5	-6.5	-7.0	6.67
10	-7.0	-7.5	-8.0	7.50
11	-7.0	-8.0	-7.5	7.50
12	-8.5	-8.0	-8.5	8.33

Magnetic Flux Density for Pair S2 and N2 = 7.46 mT

Appendix 16: Wax Removed Percentage for Different Valve Opening

Time (Hour)	Half Valve Opening		Three Quarter Valve Opening		Full Valve Opening	
	% A	% B	% A	% B	% A	% B
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.25	47.43	48.56	70.49	66.87	85.17	74.11
0.50	57.83	60.10	81.12	75.50	90.90	86.75
0.75	66.14	66.73	84.87	79.86	93.00	89.88
1.00	70.77	70.26	86.50	81.77	93.28	91.23
1.25	73.06	72.39	87.00	82.80	93.20	91.20
1.50	73.56	73.30	87.23	83.26	93.21	91.21
1.75	73.56	73.29	87.21	83.24	93.18	91.19
2.00	73.50	73.25	87.19	83.21	93.17	91.17

Appendix 17: Wax Removed Percentage for Different Crude Oil Temperature

Time (Hour)	40°C		35°C		30°C		25°C	
	% A	% B	% A	% B	% A	% B	% A	% B
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.25	87.17	75.11	86.21	74.78	85.90	74.48	85.17	74.11
0.50	95.79	96.68	95.06	96.29	92.98	91.52	90.90	86.75
0.75	96.72	96.70	96.00	96.10	94.50	92.99	93.00	89.88
1.00	96.79	95.54	96.64	95.90	94.96	93.56	93.28	91.23
1.25	97.00	95.40	96.96	95.85	95.12	93.54	93.20	91.20
1.50	98.16	96.30	96.98	95.81	95.13	93.52	93.21	91.21
1.75	99.00	97.00	97.02	95.90	95.15	93.56	93.18	91.19
2.00	99.31	98.24	97.06	95.99	95.17	93.61	93.17	91.17

Appendix 18: Wax Removed Percentage for Different Number of Magnet

Time (Hour)	4magnet		2magnet	
	% A	% B	% A	% B
0.00	0.00	0.00	0.00	0.00
0.25	85.17	74.11	79.43	74.11
0.50	90.90	86.75	88.83	86.75
0.75	93.00	89.88	91.14	89.88
1.00	93.28	91.23	91.77	91.23
1.25	93.20	91.20	92.06	91.21
1.50	93.21	91.21	92.05	91.21
1.75	93.18	91.19	92.06	91.20
2.00	93.17	91.17	92.00	91.16

Appendix 19: Material Safety Data Sheet for Dulang Crude Oil

Section 1 - CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: CRUDE OIL, DULANG

SYNONYMS: Crude, Crude Petroleum

PROPER SHIPPING NAME: PETROLEUM CRUDE OIL

PRODUCT USE: Crude oil.

SUPPLIER:

Company:	PETRONAS Carigali Sdn. Bhd.
Address:	Peninsular Malaysia Operations, PETRONAS Office Complex, 24300 Kertih, Kemaman, MALAYSIA
Telephone:	+60 9 8667722
Fax:	+60 9 8667922

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Section 2 - HAZARDS IDENTIFICATION

RISK

- Highly flammable.
- Irritating to respiratory system.
- May cause CANCER.
- Danger of serious damage to health by prolonged exposure through inhalation, in contact with skin and if swallowed.
- Danger of serious damage to health by prolonged exposure through inhalation.
- May cause lung damage if swallowed.
- Inhalation, skin contact and/or ingestion may produce health damage.
- Cumulative effects may result following exposure.
- May produce discomfort of the eyes and skin.
- Vapours potentially cause drowsiness and dizziness.

SAFETY

- Keep locked up.
- Keep away from sources of ignition. No smoking.
- Keep container in a well ventilated place.
- Avoid exposure - obtain special instructions before use.
- To clean the floor and all objects contaminated by this material, use water and detergent.
- Keep container tightly closed.

- This material and its container must be disposed of in a safe way.
- Keep away from food, drink and animal feeding stuffs.
- Take off immediately all contaminated clothing.
- In case of contact with eyes, rinse with plenty of water and contact Doctor or local health authorities.
- If you feel unwell contact Doctor or local health authorities. (Show the label if possible).

Section 3 – PROPERTIES

Colour	Brown to black liquid	
Density at 15 C	0.8382	Kg/l
API gravity	37.23	
Sulphur	0.07	% by weight
Ashphaltenes	0.32	% by weight
Wax content	19	% by weight
Total acid number	0.321	Mg KOH/g
Kinematic viscosity	5.441	cSt at 40 C
Kinematic viscosity	2.931	cSt at 70 C
RVP	Not available due to high pour point	
Flash point	38 C	
Pour point	36 C	
Gross calorific value	45.295	MJ/kg

Section 4 - FIRST AID MEASURES

SWALLOWED

- If spontaneous vomiting appears imminent or occurs, hold patient's head down lower than their hips to help avoid possible aspiration of vomitus.
- If swallowed do NOT induce vomiting.
- If vomiting occurs, lean patient forward or place on left side (head-down position, if possible) to maintain open airway and prevent aspiration.
- Observe the patient carefully.
- Never give liquid to a person showing signs of being sleepy or with reduced awareness; i.e. becoming unconscious.
- Give water to rinse out mouth, then provide liquid slowly and as much as casualty can comfortably drink.
- Seek medical advice.
- Avoid giving milk or oils.
- Avoid giving alcohol.

EYE

- If this product comes in contact with the eyes:
- Wash out immediately with fresh running water.
- Ensure complete irrigation of the eye by keeping eyelids apart and away from eye and moving the eyelids by occasionally lifting the upper and lower lids.
- If pain persists or recurs seek medical attention.
- Removal of contact lenses after an eye injury should only be undertaken by skilled personnel.

SKIN

If skin contact occurs:

- Immediately remove all contaminated clothing, including footwear
- Flush skin and hair with running water (and soap if available).
- Seek medical attention in event of irritation.

INHALED

- If fumes or combustion products are inhaled remove from contaminated area.
- Lay patient down. Keep warm and rested.
- Prostheses such as false teeth, which may block airway, should be removed, where possible, prior to initiating first aid procedures.
- Apply artificial respiration if not breathing, preferably with a demand valve resuscitator, bag-valve mask device, or pocket mask as trained. Perform CPR if necessary.
- Transport to hospital, or doctor.

NOTES TO PHYSICIAN

Any material aspirated during vomiting may produce lung injury. Therefore emesis should not be induced mechanically or pharmacologically. Mechanical means should be used if it is considered necessary to evacuate the stomach contents; these include gastric lavage after endotracheal intubation. If spontaneous vomiting has occurred after ingestion, the patient should be monitored for difficult breathing, as adverse effects of aspiration into the lungs may be delayed up to 48 hours.
For acute or short term repeated exposures to petroleum distillates or related hydrocarbons:

- Primary threat to life, from pure petroleum distillate ingestion and/or inhalation, is respiratory failure.If fumes or combustion products are inhaled remove from contaminated area
- Patients should be quickly evaluated for signs of respiratory distress (e.g. cyanosis, tachypnoea, intercostal retraction, obtundation) and given oxygen. Patients with inadequate tidal volumes or poor arterial blood gases (pO2 50 mm Hg) should be intubatedLay patient down. Keep warm and rested.
- Arrhythmias complicate some hydrocarbon ingestion and/or inhalation and electrocardiographic evidence of myocardial injury has been reported; intravenous lines and cardiac monitors should be established in obviously

symptomatic patients. The lungs excrete inhaled solvents, so that hyperventilation improves clearance.

- A chest x-ray should be taken immediately after stabilisation of breathing and circulation to document aspiration and detect the presence of pneumothoraxProstheses such as false teeth, which may block airway, should be removed, where possible, prior to initiating first aid procedures.
- Epinephrine (adrenalin) is not recommended for treatment of bronchospasm because of potential myocardial sensitisation to catecholamines. Inhaled cardioselective bronchodilators (e.g. Alupent, Salbutamol) are the preferred agents, with aminophylline a second choiceApply artificial respiration if not breathing, preferably with a demand valve resuscitator, bag-valve mask device, or pocket mask as trained. Perform CPR if necessary.
- Lavage is indicated in patients who require decontamination; ensure use of cuffed endotracheal tube in adult patients. [Ellenhorn and Barceloux: Medical ToxicologyTransport to hospital, or doctor.

Section 5 - FIRE FIGHTING MEASURES

EXTINGUISHING MEDIA

- Foam.
- Dry chemical powder.
- BCF (where regulations permit).
- Carbon dioxide.
- Water spray or fog - Large fires only.

FIRE FIGHTING

- Alert Fire Brigade and tell them location and nature of hazard.
- May be violently or explosively reactive.
- Wear full body protective clothing with breathing apparatus.
- Prevent, by any means available, spillage from entering drains or waterway.
- Consider evacuation (or protect in place).
- Fight fire from a safe distance, with adequate cover.
- If safe, switch off electrical equipment until vapour fire hazard removed.
- Use water delivered as a fine spray to control fire and cool adjacent area.
- Avoid spraying water onto liquid pools.
- DO NOT approach containers suspected to be hot.
- Cool fire exposed containers with water spray from a protected location.
- If safe to do so, remove containers from path of fire.

FIRE/EXPLOSION HAZARD

- Liquid and vapour are highly flammable.
- Severe fire hazard when exposed to heat, flame and/or oxidisers.
- Vapour may travel a considerable distance to source of ignition.
- Heating may cause expansion or decomposition leading to violent rupture of containers.
- On combustion, may emit toxic fumes of carbon monoxide (CO).

Combustion products include:

- carbon dioxide (CO_2)
- nitrogen oxides (NO_x)
- sulfur oxides (SO_x)
- metal oxides
- other pyrolysis products typical of burning organic material

FIRE INCOMPATIBILITY

Avoid contamination with oxidising agents i.e. nitrates, oxidising acids, chlorine bleaches, pool chlorine etc. as ignition may result

Section 6 - ACCIDENTAL RELEASE MEASURES

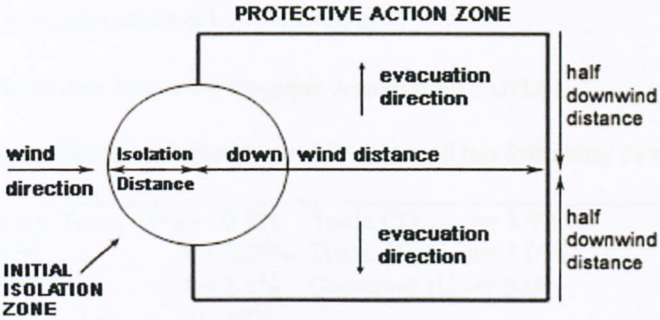
MAJOR SPILLS

- Clear area of personnel and move upwind.
- Alert Fire Brigade and tell them location and nature of hazard.
- May be violently or explosively reactive.
- Wear full body protective clothing with breathing apparatus.
- Prevent, by any means available, spillage from entering drains or water course.
- Consider evacuation (or protect in place).
- No smoking, naked lights or ignition sources.
- Increase ventilation.
- Stop leak if safe to do so.
- Water spray or fog may be used to disperse / absorb vapour.
- Contain spill with sand, earth or vermiculite.
- Use only spark-free shovels and explosion proof equipment.
- Collect recoverable product into labelled containers for recycling.
- Absorb remaining product with sand, earth or vermiculite.
- Collect solid residues and seal in labelled drums for disposal.
- Wash area and prevent runoff into drains.
- If contamination of drains or waterways occurs, advise emergency services.
- Clear area of personnel and move upwind.
- Alert Fire Brigade and tell them location and nature of hazard.
- Wear breathing apparatus plus protective gloves.
- Prevent, by any means available, spillage from entering drains or water course.
- Stop leak if safe to do so.
- Contain spill with sand, earth or vermiculite.
- Collect recoverable product into labelled containers for recycling.
- Neutralize/decontaminate residue.
- Collect solid residues and seal in labelled drums for disposal.
- Wash area and prevent runoff into drains.
- After clean up operations, decontaminate and launder all protective clothing and equipment before storing and re-using.
- If contamination of drains or waterways occurs, advise emergency services.

MINOR SPILLS

- Remove all ignition sources.
- Clean up all spills immediately.
- Avoid breathing vapours and contact with skin and eyes.
- Control personal contact by using protective equipment.
- Contain and absorb small quantities with vermiculite or other absorbent material.
- Wipe up.
- Collect residues in a flammable waste container.

PROTECTIVE ACTIONS FOR SPILL



FOOTNOTES

1 PROTECTIVE ACTION ZONE is defined as the area in which people are at risk of harmful exposure. This zone assumes that random changes in wind direction confines the vapour plume to an area within 30 degrees on either side of the predominant wind direction, resulting in a crosswind protective action distance equal to the downwind protective action distance.

2 PROTECTIVE ACTIONS should be initiated to the extent possible, beginning with those closest to the spill and working away from the site in the downwind direction. Within the protective action zone a level of vapour concentration may exist resulting in nearly all unprotected persons becoming incapacitated and unable to take protective action and/or incurring serious or irreversible health effects.

3 INITIAL ISOLATION ZONE is determined as an area, including upwind of the incident, within which a high probability of localised wind reversal may expose nearly all persons without appropriate protection to life-threatening concentrations of the material.

4 SMALL SPILLS involve a leaking package of 200 litres (55 US gallons) or less, such as a drum (jerrican or box with inner containers). Larger packages leaking less than 200 litres and compressed gas leaking from a small cylinder are also considered "small spills". LARGE SPILLS involve many small leaking packages or a leaking package of greater than 200 litres, such as a cargo tank, portable tank or a "one-tonne" compressed gas cylinder.

5 Guide 128 is taken from the US DOT emergency response guide book.

6 IERG information is derived from CANUTEC - Transport Canada.

EMERGENCY RESPONSE PLANNING GUIDELINES (ERPG)

The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour WITHOUT experiencing or developing
life-threatening health effects is:
petroleum crude oil 500 mg/m^3
irreversible or other serious effects or symptoms which could impair an individual's ability to take protective action is:
petroleum crude oil 500 mg/m^3
other than mild, transient adverse effects without perceiving a clearly defined odour is:
petroleum crude oil 500 mg/m^3
The threshold concentration below which most people. will experience no appreciable risk of health effects:
petroleum crude oil 500 mg/m^3

American Industrial Hygiene Association (AIHA)

Ingredients considered according exceed the following cutoffs

Very Toxic (T+)	>= 0.1%	Toxic (T)	>= 3.0%
R50	>= 0.25%	Toxic (T)	>= 3.0%
R51	>= 2.5%	Corrosive (C)	>= 5.0%
else	>= 10%		

Where percentage is percentage of ingredient found in the mixture

SAFE STORAGE WITH OTHER CLASSIFIED CHEMICALS

X X X X X +

X: Must not be stored together
O: May be stored together with specific preventions
+: May be stored together

Section 7 - HANDLING AND STORAGE

PROCEDURE FOR HANDLING

- Use good occupational work practice.
- Observe manufacturer's storing and handling recommendations.
- Atmosphere should be regularly checked against established exposure standards
- to ensure safe working conditions.
- DO NOT allow clothing wet with material to stay in contact with skin Avoid all personal contact, including inhalation.

- Wear protective clothing when risk of exposure occurs.
- Use in a well-ventilated area.
- Prevent concentration in hollows and sumps.
- DO NOT enter confined spaces until atmosphere has been checked.
- Avoid smoking, naked lights, and heat or ignition sources.
- When handling, DO NOT eat, drink or smoke.
- Vapour may ignite on pumping or pouring due to static electricity.
- DO NOT use plastic buckets.
- Earth and secure metal containers when dispensing or pouring product.
- Use spark-free tools when handling.
- Avoid contact with incompatible materials.
- Keep containers securely sealed.
- Avoid physical damage to containers.
- Always wash hands with soap and water after handling.
- Work clothes should be laundered separately.
- Isolation Distance 25 metres
- Downwind Protection Distance 300 metres

SUITABLE CONTAINER

- Packing as supplied by manufacturer. Plastic containers may only be used if approved for flammable liquid. Check that containers are clearly labeled and free from leaks.

STORAGE INCOMPATIBILITY

- Segregate from strong oxidisers
- Avoid reaction with oxidising agents

STORAGE REQUIREMENTS

- Store in original containers in approved flame-proof area.
- No smoking, naked lights, heat or ignition sources.
- DO NOT store in pits, depressions, basements or areas where vapours may be trapped.
- Keep containers securely sealed.
- Store away from incompatible materials in a cool, dry well ventilated area.
- Protect containers against physical damage and check regularly for leaks.
- Observe manufacturer's storing and handling recommendations.

Section 8 - EXPOSURE CONTROLS / PERSONAL PROTECTION

EXPOSURE CONTROLS

Source	Material	TWA ppm	TWA mg/m^3	STEL ppm	STEL mg/m^3	Peak ppm	Peak mg/m^3	TWA F/CC
Australia Exposure Standards	benzene (Benzene)	1	3.2					

The following materials had no OELs on our records

- petroleum crude oil: CAS:8002-05-9

EMERGENCY EXPOSURE LIMITS

Material	Revised IDLH Value (mg/m3)	Revised IDLH Value (ppm)
benzene		500

MATERIAL DATA

Not available. Refer to individual constituents

INGREDIENT DATA

PETROLEUM CRUDE OIL:
Oil, mist, mineral
TLV TWA: 5 mg/m3; STEL: 10 mg/m3
NOTICEOFINTENDEDCHANGE
TLV TWA 0.2 mg/m3 inhalable fraction poorly and mildly refined A2
WARNING: This substance has been classified by the ACGIH as A2 Suspected Human Carcinogen.
As NIOSH SE7449000
CEL TWA: 350 mg/m3 (compare REL TWA NIOSH)
CEL Ceiling: 1800 mg/m3 (compare Ceiling Value NIOSH)
OSHA PEL 500 ppm, 2000 mg/3
IDLH: 1100 ppm (10% LEL)

BENZENE:
Exposure limits with "skin" notation indicate that vapour and liquid may be absorbed through intact skin. Absorption by skin may readily exceed vapour inhalation exposure. Symptoms for skin absorption are the same as for inhalation. Contact with eyes and mucous membranes may also contribute to overall exposure and may also invalidate the exposure standard.

PERSONAL PROTECTION




The following protective equipment is recommended where appropriate to the situation and conditions:

- Safety Glasses
- Chemical goggles
- Gloves
- PVC chemical resistant type
- Respirator - type A Filter of sufficient capacity

EYE

- Safety glasses with side shields.
- Chemical goggles.
- Contact lenses pose a special hazard; soft lenses may absorb irritants and all lenses concentrate them. DO NOT wear contact lenses.

HANDS/FEET

- Wear chemical protective gloves, eg. PVC.
- Wear safety footwear or safety gumboots, eg. Rubber

OTHER

- Prior to each exit from an area containing confirmed human carcinogens, employees should be required to remove and leave protective clothing and equipment at the point of exit and at the last exit of the day, to place used clothing and equipment in impervious containers at the point of exit for purposes of decontamination or disposal. The contents of such impervious containers must be identified with suitable labels. For maintenance and decontamination activities, authorized employees entering the area should be provided with and required to wear clean, impervious garments, including gloves, boots and continuous-air supplied hood.
- Prior to removing protective garments the employee should undergo decontamination and be required to shower upon removal of the garments and hood.
- Overalls.
- PVC Apron.
- PVC protective suit may be required if exposure severe.
- Eyewash unit.
- Ensure there is ready access to a safety shower.
- Employees working with confirmed human carcinogens should be provided with, and be required to wear, clean, full body protective clothing (smocks, coveralls, or long-sleeved shirt and pants), shoe covers and gloves prior to entering the regulated area.
- Employees engaged in handling operations involving carcinogens should be provided with, and required to wear and use half-face filter-type respirators with filters for dusts, mists and fumes, or air purifying canisters or cartridges. A respirator affording higher levels of protection may be substituted.
- Emergency deluge showers and eyewash fountains, supplied with potable water, should be located near, within sight of, and on the same level with locations where direct exposure is likely.

RESPIRATOR

Selection of the Class and Type of respirator will depend upon the level of breathing zone contaminant and the chemical nature of the contaminant. Protection Factors (defined as the ratio of contaminant outside and inside the mask) may also be important.

Breathing Zone Level ppm (volume)	Maximum Protection Factor	Half-face Respirator	Full-Face Respirator
1000	10	A-AUS P	-
1000	50	-	A-AUS P
5000	50	Airline *	-
5000	100	-	A-2 P
10000	100	-	A-3 P
	100+		Airline**

- Continuous Flow ** - Continuous-flow or positive pressure demand.
The local concentration of material, quantity and conditions of use determine the type of personal protective equipment required.
For further information consult site specific CHEMWATCH data (if available), or your Occupational Health and Safety Advisor.

ENGINEERING CONTROLS

For flammable liquids and flammable gases, local exhaust ventilation or a process enclosure ventilation system may be required. Ventilation equipment should be explosion-resistant.
Air contaminants generated in the workplace possess varying "escape" velocities which, in turn, determine the "capture velocities" of fresh circulating air required to effectively remove the contaminant.

Type of Contaminant:	Air Speed:
solvent, vapours, degreasing etc., evaporating from tank (in still air).	0.25-0.5 m/s (50-100 f/min.)
aerosols, fumes from pouring operations, intermittent container filling, low speed conveyer transfers, welding, spray drift, plating acid fumes, pickling (released at low velocity into zone of active generation)	0.5-1 m/s (100-200 f/min.)
direct spray, spray painting in shallow booths, drum filling, conveyer loading, crusher dusts, gas discharge (active generation into zone of rapid air motion)	1-2.5 m/s (200-500 f/min.)

Within each range the appropriate value depends on:

Lower end of the range	Upper end of the range
1: Room air currents minimal or favourable to capture	1: Disturbing room air currents

2: Contaminants of low toxicity or of nuisance value only.	2: Contaminants of high toxicity
3: Intermittent, low production.	3: High production, heavy use
4: Large hood or large air mass in motion	4: Small hood-local control only

Simple theory shows that air velocity falls rapidly with distance away from the opening of a simple extraction pipe. Velocity generally decreases with the square of distance from the extraction point (in simple cases). Therefore the air speed at the extraction point should be adjusted, accordingly, after reference to distance from the contaminating source. The air velocity at the extraction fan, for example, should be a minimum of 1-2 m/s (200-400 f/min.) for extraction of solvents generated in a tank 2 meters distant from the extraction point. Other mechanical considerations, producing performance deficits within the extraction apparatus, make it essential that theoretical air velocities are multiplied by factors of 10 or more when extraction systems are installed or used.

- Employees exposed to confirmed human carcinogens should be authorized to do so by the employer, and work in a regulated area.
- Work should be undertaken in an isolated system such as a "glove-box" . Employees should wash their hands and arms upon completion of the assigned task and before engaging in other activities not associated with the isolated system.
- Within regulated areas, the carcinogen should be stored in sealed containers, or enclosed in a closed system, including piping systems, with any sample ports or openings closed while the carcinogens are contained within.
- Open-vessel systems are prohibited.
- Each operation should be provided with continuous local exhaust ventilation so that air movement is always from ordinary work areas to the operation.
- Exhaust air should not be discharged to regulated areas, non-regulated areas or the external environment unless decontaminated. Clean make-up air should be introduced in sufficient volume to maintain correct operation of the local exhaust system.
- For maintenance and decontamination activities, authorized employees entering the area should be provided with and required to wear clean, impervious garments, including gloves, boots and continuous-air supplied hood. Prior to removing protective garments the employee should undergo decontamination and be required to shower upon removal of the garments and hood.
- Except for outdoor systems, regulated areas should be maintained under negative pressure (with respect to non-regulated areas).
- Local exhaust ventilation requires make-up air be supplied in equal volumes to replaced air.

Laboratory hoods must be designed and maintained so as to draw air inward at an average linear face velocity of 150 feet/ min. with a minimum of 125 feet/ min. Design and construction of the fume hood requires that insertion of any portion of the employees body, other than hands and arms, be disallowed

Section 9 – PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE

Highly flammable liquid with a petroleum odour; insoluble in water

PHYSICAL PROPERTIES

Does not mix with water.

Molecular Weight: Not Applicable	Boiling Range (°C): 84-398
Melting Range (°C): Not Available	Specific Gravity (water=1): 0.8644 15.6C
Solubility in water (g/L): Immiscible	pH (as supplied): Not Applicable
pH (1% solution): Not Applicable	Vapour Pressure (kPa): Not Available
Volatile Component (%vol): Not Available	Evaporation Rate: Not Available
Relative Vapour Density (air=1): Not Available	Flash Point (°C): 5
Lower Explosive Limit (%): Not Available	Upper Explosive Limit (%): Not Available
Autoignition Temp (°C): Not Available	Decomposition Temp (°C): Not Available
State: LIQUID	Viscosity: Not available

Section 10 – CHEMICAL STABILITY AND REACTIVITY INFORMATION

CONDITIONS CONTRIBUTING TO INSTABILITY

- Presence of incompatible materials.
- Product is considered stable.

Hazardous polymerisation will not occur

Section 11 – TOXICOLOGICAL INFORMATION

POTENTIAL HEALTH EFFECTS
ACUTE HEALTH EFFECTS
SWALLOWED

Accidental ingestion of the material may be damaging to the health of the individual. Swallowing of the liquid may cause aspiration into the lungs with the risk of chemical pneumonitis; serious consequences may result. (ICSC13733).
Ingestion of petroleum hydrocarbons can irritate the pharynx, oesophagus, stomach and small intestine, and cause swellings and ulcers of the mucous. Symptoms include a burning mouth and throat; larger amounts can cause nausea and vomiting, narcosis, weakness, dizziness, slow and shallow breathing, abdominal swelling, unconsciousness and convulsions. Damage to the heart muscle can produce heart beat irregularities, ventricular fibrillation (fatal) and ECG changes. The central nervous system can be depressed. Light species can cause a sharp tingling of the tongue and cause loss of sensation there. Aspiration can cause cough, gagging, pneumonia with swelling and bleeding.

EYE

Limited evidence or practical experience suggests, that the material may cause eye irritation in a substantial number of individuals. Prolonged eye contact may cause inflammation characterised by a temporary redness of the conjunctiva (similar to windburn).
Direct eye contact with petroleum hydrocarbons can be painful, and the corneal epithelium may be temporarily damaged. Aromatic species can cause irritation and excessive tear secretion.
The material may be irritating to the eye, with prolonged contact causing inflammation. Repeated or prolonged exposure to irritants may produce conjunctivitis.

SKIN

Skin contact with the material may damage the health of the individual; systemic effects may result following absorption.
There is some evidence to suggest that the material may cause moderate inflammation of the skin either following direct contact or after a delay of some time. Repeated exposure can cause contact dermatitis which is characterised by redness, swelling and blistering.
Entry into the blood-stream, through, for example, cuts, abrasions or lesions, may produce systemic injury with harmful effects. Examine the skin prior to the use of the material and ensure that any external damage is suitably protected.
The material may cause skin irritation after prolonged or repeated exposure and may produce on contact skin redness, swelling, the production of vesicles, scaling and thickening of the skin.

INHALED

Inhalation of aerosols (mists, fumes), generated by the material during the course of normal handling, may be damaging to the health of the individual.

CHRONIC HEALTH EFFECTS

Danger of serious damage to health by prolonged exposure.
This material can cause serious damage if one is exposed to it for long periods. It can be assumed that it contains a substance which can produce severe defects. This has been demonstrated via both short- and long-term experimentation.
Constant or exposure over long periods to mixed hydrocarbons may produce stupor with dizziness, weakness and visual disturbance, weight loss and anaemia, and reduced liver and kidney function. Skin exposure may result in drying and cracking and redness of the skin. Chronic exposure to lighter hydrocarbons can cause nerve damage, peripheral neuropathy, bone marrow dysfunction and psychiatric disorders as well as damage the liver and kidneys.
Chronic exposure to benzene may cause headache, fatigue, loss of appetite and lassitude with incipient blood effects including anaemia and blood changes. Benzene is a myelotoxicant known to suppress bone- marrow cell proliferation and to induce haematologic disorders in humans and animals. Signs of benzene-induced aplastic anaemia include suppression of leukocytes (leukopenia), red cells (anaemia), platelets (thrombocytopenia) or all three cell types (pancytopenia). Classic symptoms include weakness, purpura, and haemorrhage. The most significant toxic effect is insidious and often reversible injury to the blood forming tissue. Leukaemia may develop. Occupational exposures have shown a relationship between exposure to

benzene and production of myelogenous leukaemia. There may also be a relationship between benzene exposure and the production of lymphoma and multiple myeloma. In chronic exposure, workers exhibit signs of central nervous system lesions and impairment of hearing.

TOXICITY AND IRRITATION

None assigned. Refer to individual constituents.
PETROLEUM CRUDE OIL:
unless otherwise specified data extracted from RTECS - Register of Toxic Effects of Chemical Substances.

TOXICITY	IRRITATION
Oral (rat) LD50: >4300 mg/kg	Skin (rabbit): 500 mg/24H Mild
	Eye (rabbit): 100 mg Mild

Tumorigenic - Carcinogenic by RTECS criteria.
The substance is classified by IARC as Group 3:
NOT classifiable as to its carcinogenicity to humans.
Evidence of carcinogenicity may be inadequate or limited in animal testing.
BENZENE:
unless otherwise specified data extracted from RTECS - Register of Toxic Effects of Chemical Substances.

TOXICITY	IRRITATION
Oral (man) LDLo: 50 mg/kg	SKIN (RABBIT):20 MG/24H - Moderate
Oral (rat) LD50: 930 mg/kg	Eye (rabbit): 2 mg/24h - SEVERE
Inhalation (rat) LC50: 10000 ppm/7h	
Inhalation (human) LCLo: 2000 ppm/5m	
Inhalation (man) TCLo: 150 ppm/1y - I	
Inhalation (human) TCLo: 100 ppm	

MATERIAL	CARCINOGEN	REPROTOXIN	SENSITISER	SKIN
petroleum crude oil	IARC:3			
benzene	ANMRCSCS IARC:1 AOHS NOHSC NTPA			ILOEl

CARCINOGEN
IARC: International Agency for Research on Cancer (IARC) Carcinogens: petroleum crude
oil Category: 3
CARCINOGEN
ANMRCSCS: Australia Occupational Health and Safety (Commonwealth Employment) (National
Standards) Regulations 1994 - Scheduled Carcinogenic Substance: benzene Category:
CARCINOGEN
IARC: International Agency for Research on Cancer (IARC) Carcinogens: benzene

Category:
1
CARCINOGEN
AOHS: Australia Occupational Health and Safety (Commonwealth Employment) (National
Standards) Regulations 1994 - Scheduled Carcinogenic Substance: benzene
Circumstance: When contained in a feedstock containing more than 50% of benzene by
volume
CARCINOGEN
NOHSC: Australia Exposure Standards - Carcinogens: benzene
Carcinogen Category: 1
CARCINOGEN
NTPA: US National Toxicology Program (NTP) 11th Report Part A Known to be Human
Carcinogens: benzene Category:

REPROTOXIN
ILOEl: ILO Chemicals in the electronics industry that have toxic effects on reproduction: benzene

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Section 12 – ECOLOGICAL INFORMATION

Drinking Water Standards:
hydrocarbon total: 10 ug/l (UK max.).
DO NOT discharge into sewer or waterways.
Refer to data for ingredients, which follows:
PETROLEUM CRUDE OIL:
DO NOT discharge into sewer or waterways.
BENZENE:

Hazardous Air Pollutant:	Yes
Fish LC50 (96hr.) (mg/l):	32
BCF<100:	24
log Kow (Prager 1995):	2.31
log Kow (Sangster 1997):	2.13
log Pow (Verschueren 1983):	2.13
Half- life Soil - High (hours):	384
Half- life Soil - Low (hours):	120
Half- life Air - High (hours):	501
Half- life Air - Low (hours):	50.1
Half- life Surface water - High (hours):	384
Half- life Surface water - Low (hours):	120
Half- life Ground water - High (hours):	17280
Half- life Ground water - Low (hours):	240
Aqueous biodegradation - Aerobic - High (hours):	384
Aqueous biodegradation - Aerobic - Low (hours):	120
Aqueous biodegradation - Anaerobic - High (hours):	17280

Aqueous biodegradation - Anaerobic - Low (hours):	2688
Aqueous biodegradation - Removal secondary treatment - High (hours):	100%
Aqueous biodegradation - Removal secondary treatment - Low (hours):	44%
Aqueous photolysis half- life - High (hours):	16152
Aqueous photolysis half- life - Low (hours):	2808
Photolysis maximum light absorption - High (nano- m):	268
Photolysis maximum light absorption - Low (nano- m):	239
Aqueous photolysis half- life - High (hours):	16152
Aqueous photolysis half- life - Low (hours):	2808
Photooxidation half- life water - High (hours):	3.20E+05
Photooxidation half- life water - Low (hours):	8021
Photooxidation half- life air - High (hours):	501
Photooxidation half- life air - Low (hours):	50.1

The lower molecular weight hydrocarbons are expected to form a "slick" on the surface of waters after release in calm sea conditions. This is expected to evaporate and enter the atmosphere where it will be degraded through reaction with hydroxy radicals.
Some of the material will become associated with benthic sediments, and it is likely to be spread over a fairly wide area of sea floor. Marine sediments may be either aerobic or anaerobic. The material, in probability, is biodegradable, under aerobic conditions (isomerised olefins and alkenes show variable results). Evidence also suggests that the hydrocarbons may be degradable under anaerobic conditions although such degradation in benthic sediments may be a relatively slow process. Under aerobic conditions the material will degrade to water and carbon dioxide, while under anaerobic processes it will produce water, methane and carbon dioxide. Based on test results, as well as theoretical considerations, the potential for bioaccumulation may be high. Toxic effects are often observed in species such as blue mussel, daphnia, freshwater green algae, marine copepods and amphipods.
Drinking Water Standards:
hydrocarbon total: 10 ug/l (UK max.).
DO NOT discharge into sewer or waterways.
log Kow: 1.95-2.15
log Koc: 1.7-2
Koc: 98
log Kom: 1.04-2.56
Half-life (hr) air: 2.4-501
Half-life (hr) H2O surface water: 4.81-384
Half-life (hr) H2O ground: 240-17280
Half-life (hr) soil: 48-922
Henry's Pa m^3 /mol: 441-595
Henry's atm m^3 /mol: 5.43E-03
BOD 5 if unstated: 2.18
COD: 0.25-2.8
ThOD: 3.1
BCF: 3.5-3.9
Log BCF: 0.54-1.48
Toxicity Fish: LC50(96)9.5-386mg/L

Toxicity invertebrate: cell mult. inhib.92-#90etox1700mg/L
Nitrif. inhib.: nil at 500mg/L
Anaerobic effects: slow degrad
Effects on algae and plankton: cell mult. inhib. >1400mg/L
Degradation Biological: slow
processes Abiotic: little photol,Rxn OH*,no hydrol
If benzene is released to the atmosphere it remains predominantly in the vapour phase.
Vapour phase benzene is not subject to direct photolysis but reacts with photochemically produced hydroxyl radicals (half-life approximately 13.4 days). Reaction time in polluted atmospheres which contain nitrogen oxide (NO) or sulfur dioxide (SO2) is accelerated (half-life 4-6 hours); products of photooxidation include phenol, nitrophenols, nitrobenzene, formic acid and peroxyacetyl nitrates.
In water, benzene is rapidly volatilised (half-life 2.7 hours).
In soil benzene undergoes rapid volatilisation; it is not absorbed, to any appreciable degree, by sediments.
Benzene does not bioaccumulate in the food chain.
Drinking Water Standards:
hydrocarbon total: 10 ug/l (UK max.)
benzene: 10 ug/l (WHO guideline)
Soil Guidelines: Dutch Criteria:
0.05 mg/kg (detection limit) target
1 mg/kg (intervention)

Air Quality Standards:
1 ppb averaging time 1 year (UK)
No safe level recommended due to carcinogenic properties (WHO Guideline)

Section 13 – DISPOSAL CONSIDERATIONS

- Containers may still present a chemical hazard/ danger when empty.
- Return to supplier for reuse/ recycling if possible.

Otherwise:

- If container can not be cleaned sufficiently well to ensure that residuals do not remain or if the container cannot be used to store the same product, then puncture containers, to prevent re-use, and bury at an authorised landfill.
- Where possible retain label warnings and MSDS and observe all notices pertaining to the product.

Section 14 – TRANSPORTATION INFORMATION

Labels Required: FLAMMABLE LIQUID
HAZCHEM: 3WE

UNDG:

Dangerous Goods Class:	3	Subrisk:	None, None
UN Number:	1267	Packing Group:	II

Shipping Name:PETROLEUM CRUDE OIL

Air Transport IATA:

ICAO/IATA Class:	3	ICAO/IATA Subrisk:	None
UN/ID Number:	1267	Packing Group:	II
Special provisions:	A3		

Shipping Name: PETROLEUM CRUDE OIL

Maritime Transport IMDG:

IMDG Class:	3	IMDG Subrisk:	None
UN Number:	1267	Packing Group:	II
EMS Number:	F-E,S-E	Special provisions:	None

Shipping Name: PETROLEUM CRUDE OIL

Section 15 – REGULATORY INFORMATION

POISONS SCHEDULE

None

REGULATIONS

Petronas Carigali Malaysia Crude Oil (CAS: None):
No regulations applicable
petroleum crude oil (CAS: 8002- 05- 9) is found on the following regulatory lists;
Australia High Volume Industrial Chemical List (HVICL)
Australia Inventory of Chemical Substances (AICS)
International Agency for Research on Cancer (IARC) Carcinogens
OECD Representative List of High Production Volume (HPV) Chemicals
benzene (CAS: 71- 43- 2) is found on the following regulatory lists;
Australia - Australian Capital Territory - Environment Protection Regulation: Ambient environmental standards (Domestic water supply - organic compounds)
Australia - Australian Capital Territory - Environment Protection Regulation: Pollutants entering waterways taken to cause environmental harm (Aquatic habitat)
Australia - Australian Capital Territory Environment Protection Regulation Ecosystem maintenance - Organic chemicals - Non- pesticide anthropogenic organics
Australia - Australian Capital Territory Environment Protection Regulation Pollutants entering waterways - Domestic water quality
Australia - New South Wales Hazardous Substances Prohibited for Specific Uses
Australia - New South Wales Hazardous Substances Requiring Health Surveillance
Australia - New South Wales Notifiable Carcinogens

Australia - Tasmania Hazardous Substances Requiring Health Surveillance
Australia - Victoria - Hazardous Substances - Carcinogens Schedule 2 - No Longer Valid
Australia - Western Australia Carcinogenic substances to be used only for purposes approved by the Commissioner
Australia - Western Australia Hazardous Substances Requiring Health Surveillance
Australia Exposure Standards
Australia Exposure Standards Currently Under Review
Australia Hazardous Substances Requiring Health Surveillance
Australia High Volume Industrial Chemical List (HVICL)
Australia Inventory of Chemical Substances (AICS)
Australia National Model Regulations for the Control of Scheduled Carcinogenic Substances
Australia National Pollutant Inventory
Australia Occupational Health and Safety (Commonwealth Employment) (National Standards) Regulations 1994 - Hazardous Substances Requiring Health Surveillance
Australia Occupational Health and Safety (Commonwealth Employment) (National Standards) Regulations 1994 - Scheduled Carcinogenic Substance
Australia Standard for the Uniform Scheduling of Drugs and Poisons (SUSDP) - Appendix E (Part 2)
Australia Standard for the Uniform Scheduling of Drugs and Poisons (SUSDP) - Appendix F (Part 3)
Australia Standard for the Uniform Scheduling of Drugs and Poisons (SUSDP) - Appendix J (Part 2)
Australia Standard for the Uniform Scheduling of Drugs and Poisons (SUSDP) - Schedule 7
International Agency for Research on Cancer (IARC) Carcinogens
OECD Representative List of High Production Volume (HPV) Chemicals

Section 16 – OTHER INFORMATION

REPRODUCTIVE HEALTH GUIDELINES

Established occupational exposure limits frequently do not take into consideration reproductive end points that are clearly below the thresholds for other toxic effects. Occupational reproductive guidelines (ORGs) have been suggested as an additional standard. These have been established after a literature search for reproductive no -observed-adverse effect-level (NOAEL) and the lowest-observed-adverse-effect-level (LOAEL). In addition the US EPA's procedures for risk assessment for hazard identification and dose-response assessment as applied by NIOSH were used in the creation of such limits. Uncertainty factors (UFs) have also been incorporated.

Ingredient	ORG	UF	Endpoint	CR	Adeq TLV
benzene	0.05 mg/m3	1000	D	1.4	-

These exposure guidelines have been derived from a screening level of risk assessment and should not be construed as unequivocally safe limits. ORGS represent an 8-hour time -weighted average unless specified otherwise.

CR = Cancer Risk/10000; UF = Uncertainty factor:

TLV believed to be adequate to protect reproductive health:

LOD: Limit of detection

Toxic endpoints have also been identified as:

D = Developmental; R = Reproductive; TC = Transplacental carcinogen

Jankovic J., Drake F.: A Screening Method for Occupational Reproductive American Industrial Hygiene Association Journal 57: 641-649 (1996).

EXPOSURE STANDARD FOR MIXTURES

"Worst Case" computer-aided prediction of spray/ mist or fume/ dust components and concentration: Composite Exposure Standard for Mixture (TWA) :350 mg/m³. Operations which produce a spray/mist or fume/dust, introduce particulates to the breathing zone. If the breathing zone concentration of ANY of the components listed below is exceeded, "Worst Case" considerations deem the individual to be overexposed. Component Breathing Zone ppm Breathing Zone mg/m3 Mixture Conc (%).

Component	Breathing Zone (mg/m³)	Mixture Conc (%)
petroleum crude oil	350.0000	100.0